Series II, Volume 1 December 27, 1956 Number 8

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1956 WINTER MEETING ON THE WEST COAST

AT THE

U. S. NAVAL POSTGRADUATE SCHOOL, MONTEREY, CALIFORNIA

December 27, 28, and 29, 1956

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Table of Contents

Programme of the 1956 Winter Meeting on the West Coast to be held at Monterey, California 372

Author Index to Papers Presented at Monterey Meeting 399

Announcement of the meeting at Norman, Oklahoma 400

Calendar of future meetings and deadlines . . . 401

Minutes of the 1956 Autumn Meeting of the Ohio Section 402

Cumulative Author Index of abstracts appearing in this volume of the Bulletin 404

December 27, 1956 Series II, Vol. 1, No. 8

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1956 Winter Meeting on the West Coast at the U. S. Naval Postgraduate School, Monterey, California, December 27, 28, and 29, 1956

THE 1956 winter meeting on the Pacific Coast of the American Physical Society will be held at the U. S. Naval Postgraduate School in Monterey, California, on **Thursday, Friday, and Saturday, December 27, 28, and 29.** This is the first time that the Society has met in that locality. (Some people inferred from the preliminary announcements that this meeting would be held in Monterey: they should take note of the spelling.) The school has been in existence since 1909 but has only recently been transferred to Monterey. The meeting therefore celebrates the addition of a new school to the West Coast.

The Monterey Chamber of Commerce Convention Bureau will be very happy to book reservations for members of the Society. Members should address themselves to Mrs. Helen H. Hoxie, Convention Bureau, Box 489, Monterey, California. Those arriving by plane will find that transportation will be provided from the airport to their motels if they will indicate time of arrival in their request for accommodations. Motel rooms will be available at the Mark Thomas Inn, just across Fremont Avenue from the Navy School (50 rooms) and at the Casa Munras Motel (100 rooms). At both of these motels single rooms are $8, doubles $10, and twins $12. If these are exhausted, the Convention Bureau will have any number of rooms up to about a thousand available elsewhere. The Mark Thomas Inn is the only really close one; the others are nearby. Dormitory housing for students and others will be available at Asilomar, which is 20 minutes by car from the school, for $3 per person. The excellent arrangements for the Society that have been described above have been prepared by the Chairman of the Local Committee, Professor E. C. Crittenden, Jr. This programme has been arranged with the help of Professors W. K. H. Panofsky, N. L. Oleson, C. Zener, C. Kittel, S. D. Drell, and R. F. Bacher.

This programme consists of 124 contributed papers and 29 invited papers. It has therefore been impossible to avoid parallel sessions during the meeting, and in fact at one point there will be four parallel sessions. However, it is hoped that the sessions have been arranged so as to enable most of the auditors to attend all the sessions that they find interesting. This meeting, from the viewpoint of the number of contributed papers, is one of the larger meetings that we have had on the west coast. Undoubtedly the attractions of Monterey have had something to do with it.

Most of the **sessions** will be held in Spanagel Hall. The sessions that are expected to be most heavily attended will take place in the very large and elegant King Hall. One session, Session L, will be in Herrmann Hall in the room interestingly named the Copper Cup.

The **registration desk** will be in the lobby of Spanagel Hall. The registration fee will be $1. At the desk, tickets for the banquet will be sold for $2.25 per plate until 1 P.M. Friday.

The **banquet of the Society** will be held on Friday evening at 8 o'clock in the Bali Room of Herrmann Hall which is the old Del Monte Hotel building which some members may remember. The principal speaker will be Professor P. Kusch and the presiding officer will be Professor E. P. Wigner, President of the Society. Rear Admiral Earl E. Stone, Superintendent of the U. S. Naval Postgraduate School, will welcome the Society at the dinner. An interesting feature of the dinner this time will be the dance orchestra which will be available, free of charge, for the Society, after the business part of the dinner is over. Members of the Society and their guests are welcome to enjoy the after-dinner music and dancing.

A very ambitious and interesting **ladies' programme** has been arranged by the wives of the Physics Department staff. There will be a registration desk for the ladies in the lobby of Spanagel

Hall, close to the main registration desk. The ladies may sign up for the two following ambitious programs, among other things: Thursday there will be a visit arranged to the historic buildings of Monterey or to the Carmel Valley. Transportation and guides for these visits will be provided by the Monterey Hostess Committee. Friday, a tour of the 17-mile drive, with lunch at the Del Monte Lodge, followed by a visit to Carmel with time provided for a visit to the shops in Carmel, will be provided. The price will be $2.50 for everything, including transportation (which is provided free by the Chamber of Commerce) and the gate admission to Del Monte Forest (normally $.75). Departure for this journey will be about 10 A.M. from the Navy School.

Professor George Barnes, President of the **Northern California Association of Physics Teachers,** has called for a one-day meeting on **Friday, December 28,** for the Association. The meeting will be held in room 136, Spanagel Hall. A panel discussion is planned on methods to obtain better coordination between high school and college physics training. This discussion will take up all but the first hour of the afternoon session. The first hour of the afternoon will be devoted to the business meeting; therefore the panel discussion will be started at 2 P.M. Members of the panel will be Professor S. W. Leifson, University of Nevada; Professor Paul DeH. Hurd, Stanford School of Education; Mr. D. O. Hall, Placer Junior College; and Mr. Henry C. Martin, Palo Alto Senior High School. Mr. Fred J. Clark of Stockton College will act as moderator. There will be two more high school representatives chosen before the time of the meeting. The morning session will be taken up by the presentation of papers on the teaching of physics and related subjects. The U. S. Naval Postgraduate School has recently successfully negotiated for a teaching reactor. This reactor is being installed and will be in operation during the meeting for those of the Society who would like to see it.

For **luncheon** the Trident Room and Silk Horse Lounge operate as a restaurant with a buffet style lunch and will be open all three days of the meeting. The cafeteria, under the lecture hall, will operate Thursday and Friday, and will also be open from 9 A.M. to 4 P.M. for snacks and coffee. The lovely faculty lounge, room 200, on the floor immediately above the lobby of Spanagel Hall, will be available for members of the Society during the meetings. Preceding the dinner Friday, the Trident Room (bar), Copper Cup Room, and the Silk Horse Lounge, will be open for cocktails. They also will be open generally in the afternoon and on into the evening.

Post-deadline, 10-minute papers of sufficient importance to warrant their inclusion in a special supplementary program will be considered by the Local Secretary if the abstracts are received not later than Saturday, December 22, at the office of the Local Secretary for the Pacific Coast (see address below). These papers will be presented following a session that will be designated on a blackboard in the lobby of Spanagel Hall.

Errata pertaining to abstracts in this issue will be published in a subsequent issue of the Bulletin if received not later than Monday, January 7, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstracts marked with corrections. Write out the corrections in the form "Instead of . . . read. . . ." Add nothing.

W. A. NIERENBERG
Local Secretary for the Pacific Coast
University of California
Berkeley 4, California

EPITOME OF THE 1956 MONTEREY MEETING

(Personal names are those of invited speakers.)

Thursday Morning

10:00 A. Solid State I. Adams, Forrester, Glover, Darrow. King Hall.

10:00 B. High-Energy Physics. Contributed Papers. Spanagel 400.

10:00 C. General Physics. Contributed papers. Spanagel 421.

Thursday Afternoon

2:30 D. Theoretical Physics. Bloch, Pines, Uehling, Watson. Spanagel 400.

1:30 E. Electron Physics. Wehner, Emeleus, Fite, Loeb, Phelps. King Hall.

1:00 F. Solid State I. Contributed papers. Spanagel 421.

Friday Morning

9:00 G. Low-Energy Nuclear Physics. Moszkowski, Hubbs, Helmholz, Goldhaber, Allison. King Hall.

9:00 H. Solid State II. Contributed papers. Spanagel 400.

9:30 I. Theory. Contributed papers. Spanagel 421.

Friday Afternoon

2:00 J. Solid State II. Kurti, Feher, Knight, Bloom. King Hall.

2:00 K. Mesons I. Contributed papers. Spanagel 421.

1:30 L. Scattering. Contributed papers. Herrmann Hall, Copper Cup Room.

2:30 M. Low-Energy Nuclear Physics. Contributed papers. Spanagel 400.

Friday Evening

8:00 Banquet of the American Physical Society. Kusch. Bali Room.

Saturday Morning

10:15 N. Astrophysics. Greenstein, Lauritsen, Fowler, Hoyle. King Hall.

9:00 O. Mesons II. Contributed papers. Spanagel 421.

9:00 P. Electron Physics I. Contributed papers. Spanagel 400.

Saturday Afternoon

2:00 Q. High-Energy Physics. Sands, Streib, Cork. King Hall.

1:30 R. Electron Physics II. Contributed papers. Spanagel 421.

1:30 S. Nuclear and Electron Resonance. Contributed papers. Spanagel 400.

PROGRAMME

THURSDAY MORNING AT 10:00

King Hall

(J. R. PELLAM, presiding)

Invited Papers

A1. Some Quantum Effects in Semiconductors in Very High Magnetic Field. E. N. ADAMS, *Westinghouse Electric Corporation.* (30 min.)

A2. Photoelectric Mixing of Incoherent Light. A. THEODORE FORRESTER, *Westinghouse Electric Corporation.* (30 min.)

A3. Superconductivity at Millimeter-Microwave and Far Infrared Frequencies. R. E. GLOVER III, *University of North Carolina and University of California, Berkeley.* (30 min.)

A4. The Hall Effect: a Study in History. K. K. DARROW, *American Physical Society.* (30 min.)

THURSDAY MORNING AT 10:00

Spanagel 400

(L. W. ALVAREZ presiding)

High-Energy Physics

B1. Production of Polarized Bremsstrahlung by 600-Mev Electrons.* R. E. TAYLOR AND R. F. MOZLEY, *Stanford University.*—Calculations indicate that bremsstrahlung from high-energy electrons should be partially plane polarized. At a fixed photon energy, the polarization increases with increasing electron energy and is a maximum at an angle $\sim mc^2/E_0$. The bremsstrahlung from a thin radiator placed in the beam of the 600-Mev Stanford linear accelerator is used as a source of such radiation. The small angle bremsstrahlung is observed through a small collimator 40 feet from the radiator. The angular divergence of the electron beam and its multiple scattering in the radiator are less than mc^2/E_0. The collimation of the electron beam is done 100 feet before the radiator to reduce γ-ray contamination. After passing through the radiator, the electron beam is deflected and stopped. The plane of polarization of the bremsstrahlung which passes through the γ-ray collimator is varied by steering the electron beam just before it strikes the radiator. This changes the angle between the direction of the observed bremsstrahlung and the direction of the incident electrons. At an angle such that a beam of approximately 5×10^7 equivalent quanta is obtained, 360-Mev photons have an estimated polarization of 15%.

* The research reported here was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

B2. Production of π^+ Mesons by Polarized Bremsstrahlung.* R. F. MOZLEY AND R. E. TAYLOR, *Stanford University.*—A measurement has been made of the ratio of π^+ mesons produced in hydrogen along and at right angles to the polarization vector of a beam of polarized bremsstrahlung. The mesons are detected electronically by observing the delayed $\mu\rightarrow e$ decay in plastic scintillators. In order to obtain reasonable counting rates, the angle and energy of the mesons is poorly defined, $90°\pm20°$ and 130 Mev$\pm$20 Mev. The ratio of production along and at right angles to the polarization vector is 0.95 ± 0.01. No measurement of the amount of polarization has been made. Qualitatively the asymmetry observed varies as suggested by theoretical estimates.[1,2] Using a value of polarization estimated as 15%, a value is obtained of $\sigma_{\parallel}/\sigma_{\perp}=0.7$. This is not in disagreement with a prediction by Dalitz[3] based on values of the electric dipole moment E_1, and magnetic dipole moment M_2 given by Watson *et al.*[4]

* The research reported here was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] M. May and G. C. Wick, Phys. Rev. **81**, 628 (1951); M. May, Phys. Rev. **84**, 265 (1951).

[2] R. Karplus and A. Reifman, University of California Radiation Laboratory Report No. 2686, 1954.

[3] R. H. Dalitz (private communication).

[4] Watson, Keck, Tollestrup, and Walker, Phys. Rev. **101**, 1159 (1956).

B3. Absolute Cross Section Measurement of Electron-Proton Scattering and the Radiative Correction.* G. W. TAUTFEST† AND W. K. H. PANOFSKY, *Stanford University.*—The absolute cross sections for electron-proton scattering at an incident electron energy of 139.5 Mev has been measured by observing the recoil protons in the angular range $54°<\gamma<78°$ of the recoil angle γ. A photographic plate technique using 50μ C2 emulsions in a special camera was used. The result is $\sigma_{\text{exp}}/\sigma_{\text{theoret}}=0.980\pm0.021$. The theoretical value includes a correction for the finite size of the proton as well as the radiative correction. Since, in this experiment the quality $(4\alpha/\pi)\ln(q/mc^2)$, where q is the momentum transfer in the process, is 5%, we consider this experiment to be confirmation for the existence of the radiative correction, but not a significant measurement of its magnitude.

* The research reported here was supported jointly by the Office of Naval Research and the U. S. Atomic Energy Commission.

† Now at the Department of Physics, Purdue University, Lafayette, Indiana.

B4. Proton-Proton Collisions at 6.2 Bev.* R. M. KALBACH, R. GERSTEN, Y. B. KIM, J. J. LORD, AND C. H. TSAO,† *University of Washington.*—A stack of G-5 emulsions has been exposed to the internal 6.2-Bev proton beam of the Berkeley Bevatron. The emulsions were searched for nuclear collisions and for cases of the production of heavy unstable particles. While most of the proton collisions were with the Ag and Br composing the emulsion, about 300 looked like proton-proton collisions. Analysis of those events having an even number of emitted particles as compared to those having an odd number

provided a first correction for collisions with heavy nuclei which looked like proton-proton collisions. The most probable number of charged particles (protons and mesons) emitted in a proton-proton collision was found to be four. The energy and angular distribution of the secondary tracks derived from multiple scattering and grain density will be reported.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Assisted by a grant from the National Science Foundation.

B5. Triplet Production by Photons in Hydrogen.* JOHN D. ANDERSON, DUANE C. GATES, THOMAS L. JENKINS, ROBERT W. KENNEY, CHARLES A. MCDONALD, JR., AND WILLIAM P. SWANSON, *University of California, Berkeley.*—The 340-Mev bremsstrahlung beam from the Berkeley synchrotron was used to produce electron pairs and triplets in the 4-in. liquid-hydrogen bubble chamber. When the momentum transfer to the recoil electron was small, a triplet was indistinguishable from a pair. The case of large momentum transfer has been studied for the range in which the momentum p of the recoil electron is $\geq mc$. Preliminary results will be given for the partition function for the two high-energy triplet fragments and for the energy and angular distributions of the recoil electron. The triplet-production theory of Wheeler and Lamb,[1] Watson,[2] and Votruba[3] will be discussed. We wish to thank J. D. Gow, D. Parmentier, and A. J. Schwemin for providing and operating the bubble chamber for this run. The loan of the film-scanning equipment and aid in its operation by the Berkeley bubble chamber group is gratefully acknowledged.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] J. A. Wheeler and W. E. Lamb, Phys. Rev. **55**, 858 (1939).
[2] K. M. Watson, Phys. Rev. **72**, 1060 (1947).
[3] V. Votruba, Bull. intern. acad. tcheque Sci. **49**, 19 (1948).

B6. Elastic Proton-Proton Scattering at 2.24, 4.40, and 6.15 Bev.* BRUCE CORK, AND WILLIAM A. WENZEL, *Radiation Laboratory, University of California, Berkeley,* AND C. W. CAUSEY, JR., *United States Naval Postgraduate School.*—Protons of the internal circulating beam of the Bevatron were scattered in a polyethylene target. Both scattered and recoil protons were detected by scintillation counters. An internal counter located within a few inches of the beam permitted measurements at laboratory angles as low as 2°. Absolute values are based on the calibration of the induction electrode (which monitors the internal beam), and are subject to a systematic uncertainty of about ±15%. The results are shown in Table I.

TABLE I. Differential cross sections in millibarns per steradian as a function of center-of-mass angle.

2.24 Bev		4.40 Bev		6.15 Bev	
$\theta_{c.m.}$	$\frac{d\sigma}{d\omega}$	$\theta_{c.m.}$	$\frac{d\sigma}{d\omega}$	$\theta_{c.m.}$	$\frac{d\sigma}{d\omega}$
14.7	22.9	10.6	22.5	7.6	30.4
23.6	12.1	14.2	20.1	11.6	27.1
29.2	7.3	17.5	14.0	15.2	11.0
44.0	1.23	21.3	6.61	20.0	6.06
57.6	0.47	24.5	3.25	20.8	3.36
70.3	0.28	28.5	2.19	23.6	1.44
93.5	0.16	37.4	0.52	27.6	0.72
		53.2	0.11		
		69.0	0.042		

* This work was done under the auspices of the U. S. Atomic Energy Commission.

B7. Neutron Multiplicities from μ Capture.* SELIG N. KAPLAN, GEORGE P. MILLBURN, BURTON J. MOYER, AND ROBERT V. PYLE, *University of California, Berkeley.*—The magnitude of the nuclear excitation induced by cosmic-ray μ mesons captured at rest has been inferred by counting the neutrons boiled off from the excited residual nucleus.[1] These measurements are being repeated, with a cadmium-loaded liquid scintillator with an average efficiency of 55% for detecting fission-spectrum neutrons. It is hoped thereby to obtain additional information about the interactions, particularly the excitation distribution. Our measurements to date give, where ν is the number of neutrons per capture, $\bar{\nu}_{Pb}=1.41\pm0.14$ and $\bar{\nu}_{Ag}=1.40\pm0.17$. The distributions actually observed, after correction for background and μ^+ mesons, are

n =	0	1	2	3	4	5	6	7
Ag	120	110	30	5	2	0	0	1
Pb	159	182	51	10	3	1	1	0

Although we have assumed the n-component contamination to be negligible, it may have contributed the higher multiplicities observed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] R. D. Sard and M. F. Crouch, *Progress in Cosmic Ray Physics*, J. G. Wilson, Editor (Interscience Publishers, Inc., New York, 1954), Vol. II, p. 3; M. Widgoff, Phys. Rev. **90**, 891 (1953).

B8. High-Energy (p,d) Pickup Reactions.* KENNETH R. GREIDER, *University of California, Berkeley* (introduced by David L. Judd).—The cross section for the high-energy (p,d) pickup reaction on carbon has been calculated, taking into consideration the interaction of the proton with all the nucleons in the nucleus as opposed to the usual Born approximation treatment that considers the interaction with the picked-up neutron only. The interaction was treated semi-empirically by using compatible elastic proton-scattering data for carbon targets. This method results in the scattering of the proton into intermediate momentum states before pickup, which enhances the wide-angle scattering over the usual Born approximation treatment. It was found that the experimental angular distributions[1] could be fitted best with a nuclear momentum-density distribution of the form $\exp(-E/14)$.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Walter Selove, Phys. Rev. **101**, 231 (1956).

B9. Total Proton-Antiproton Cross Section.* GLEN R. LAMBERTSON, BRUCE CORK, ORESTE PICCIONI,† AND WILLIAM A. WENZEL, *University of California, Berkeley.*—Negative particles from an internal Be target were deflected outward in the magnetic field of the Bevatron and channeled by a system of external magnetic quadrupole lenses to a distance of about 100 ft from the target. In the last 60 ft, six scintillation counters in fast coincidence served to detect by time of flight 300 to 600 antiprotons per hr. Following the detecting system was a liquid-hydrogen target 62 in. long and 8 in. in diameter. A 13-in. diameter scintillation counter in "good" geometry measured the absorption of antiprotons in the hydrogen target. Measured cross sections, including a small correction for forward diffraction scattering, are as follows:

$T\bar{p}$ in Mev	σ_T in mb
700	$92(1\pm0.05)$
500	$100(1\pm0.05)$
300	$104(1\pm0.13)$
190	$136(1\pm0.13)$

For the cross sections, only the statistical uncertainties are indicated. The kinetic energy in each case is accurate to ±5%.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† On leave of absence from Brookhaven National Laboratory, Upton, New York.

B10. Design of a Triple-Focusing Spectrometer for Charged Particle Analysis.* K. L. BROWN AND W. K. H. PANOFSKY, *Stanford University.*—Secondary particles from high-energy processes are most frequently emitted in a continuous energy spectrum. The number of particles collected by a magnetic analyzer is thus proportional to the product of the solid angle subtended by the analyzer aperture at the target times the energy band collected. An instrument has been designed which provides "triple focusing" in the vertical and horizontal direc-

tion and over energy. The instrument consists of two magnets of field index $n=0.27$, each bending the particles through 110° in the same direction; the second magnet cancels the energy dispersion of the first. The energy pass band is defined by a set of slits between the magnets. Details of an instrument mounted in a rotating platform for $p=350$ Mev/c will be given.

* The research reported here was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

B11. Noise Level and Momentum Spectrum in a Multiplate Cloud Chamber.* M. ANNIS,† N. F. HARMON,‡ AND R. D. SARD, *Washington University.*—A cloud chamber containing eleven 7.2 g cm^{-2} Pb plates has been operated at 3.4 km under a penetrating shower selector.[1] Scattering measurements have been made on 49 minimum-ionizing penetrating particles associated with at least one other penetrating particle. The histogram of rms angles is fitted by a calculated curve involving as parameters the standard deviation σ_1 of the noise angle distribution and the exponent $-\gamma$ of the assumed power-law differential momentum spectrum of shower particles. Fitting the histogram requires a γ of 2 to 2.5 and a σ_1 of 3 to 8 milliradians. The former agrees well with a direct magnet cloud-chamber determination[2] of 2.5 ± 0.3. The latter corresponds to a "maximum detectable momentum-velocity"[3] (standard error) of 2–5 Mev for a track traversing nine plates (18 cells).

* Supported by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission and by a grant from the Research Corporation.

† Now at Allied Research Associates Inc., Boston, Massachusetts.

‡ Now at St. Mary's College, California.

[1] N. F. Harmon, thesis, Washington University, St. Louis, 1955 (unpublished); Annis, Harmon, and Sard (to be published).

[2] K. H. Barker and C. C. Butler, Proc. Phys. Soc. (London) **A64**, 4 (1951).

[3] Annis, Bridge, and Olbert, Phys. Rev. **89**, 1216 (1953).

THURSDAY MORNING AT 10:00

Spanagel 421

(A. R. FREY presiding)

General Physics

C1. Effect of the Earth's Oblateness on the Period of a Satellite. LEON BLITZER, *University of Arizona, and The Ramo-Wooldridge Corporation.*—The effect of the earth's oblateness on the period of the latitudinal motion of a satellite in a near-circular orbit is investigated. On the assumption that the altitude is sufficiently great that atmospheric drag may be neglected and that the effects of gravitational anomalies and extra-terrestrial bodies can be disregarded, it is shown that in addition to the usual dependence on altitude the period depends as well on the inclination of the orbit to the equator. For orbits in the neighborhood of the equator the period is *less* than for an orbit at the same height around a spherical earth. The period increases with orbit inclination, and for polar orbits the period is greater than for an orbit at the same height over a spherical earth. For a satellite at a height of 300 miles the difference in periods between polar and near-equatorial orbits is 12 seconds.

C2. Oblateness Perturbations of an Elliptic Satellite's Orbit. ALBERT D. WHEELON AND LEON BLITZER, *The Ramo-Wooldridge Corporation.*—The earth's oblateness will play an interesting role in forthcoming US-IGY satellite experiments. The plane of a satellite orbit will be precessed about the earth's axis, so that the angular regression of its nodes becomes

$$\Delta\phi = J\frac{\pi}{2}\left[\frac{R}{r_1}+\frac{R}{r_2}\right]^2 \cos i,$$

where J is the coupling constant in the standard oblate potential; r_1 and r_2 are the apogee and perigee distances, respectively; and i is the orbit inclination to the equator. Analytic descriptions of the radial and latitudinal motion are given, with the satellite's burnout position and velocity components as parameters. It is suggested that the (radio) measurement of $\Delta\phi$ would determine J to a new precision.

C3. Dynamics of a Projectile Penetrating Sand. WILLIAM A. ALLEN, EARLE B. MAYFIELD, AND HARVEY L. MORRISON, *U. S. Naval Ordnance Test Station.*—The experiment reported in this paper was designed to obtain data on the dynamics of a nonrotating, conical-nosed projectile penetrating randomly packed sand. Position *versus* time measurements for the projectile in sand were obtained by means of a photographic-electronic chronograph developed for the purpose. The striking velocity v_0 of all rounds was about 700 m/sec. The negative acceleration of a 5-in. long, 0.50-caliber, 80-gram projectile was found to be roughly expressible by the equation $-dv/dt=\alpha v^2+\beta v+\gamma$, where the coefficients α, β, and γ are positive constants. This general relation includes as special cases the conventional penetration formulas of Robins-Euler, Poncelet, and Résal. A new theory of penetration is proposed based on the equation: $-dv/dt=\alpha v^2$, $v_0>v>v_e$; $-dv/dt=\beta v^2+\gamma$, $v_e>v>0$, where the coefficients α, β, γ are positive constants and $\alpha<\beta$. An abrupt transition in the drag force that occurs at the critical velocity v_e of about 100 m/sec is believed due to transition from inelastic to quasi-elastic impact.

C4. Elastic and Plastic Behavior in Simple Target-Projectile Systems. MARVIN E. BACKMAN, *U. S. Naval Ordnance Test Station.*—The dynamic interaction of steel projectiles striking aluminum alloy plates at normal incidence has been investigated for geometrically simple projectiles. Observations on the penetration craters formed by flat nose projectiles and certain idealized stress wave considerations lead to a theory of cavity formation. This can be quantitatively formulated as the relationship of the depth of penetration to impact velocity, certain functions of the characteristic impedances of the target and projectile materials, and an empirically determined dynamic elastic limit. This theory agrees with measurements for small projectiles traveling at velocities between 100 and 270 meters/second. Velocity ranges of dominantly elastic and dominantly plastic target behavior can be identified. The stress associated with the transition point is estimated to be 18 kilobars.

C5. Triple-Point Loci from Spherical Shocks Impinging on a Wedge. R. L. SCHELLENBAUM, *Sandia Corporation.*—A shock

wave striking a reflecting surface, at a sufficient angle and overpressure, develops into a Mach reflection. The triple point is the junction of the incident and reflected shock waves and the Mach stem. Taub has proposed a method whereby data obtained from plane shock waves impinging on a wedge in a shock tube may be used to predict triple-point loci of any chosen detonation. Predictions by Taub's method yielded considerably lower triple-point heights than those observed from spherical detonations over a reflecting plane. Differences in the triple-point loci of plane and spherical shock waves impinging on wedges have been observed by firing a series of 0.5-oz Pentolite charges at various distances from the apex of hardwood wedges. Resulting spherical shock wave data, when used in Taub's method for triple-point loci predictions for large-scale spherical detonations, increases prediction accuracy only at very low Mach stem heights. Taub's method appears to fail chiefly because of application of data from shock waves striking a wedge in free air (no reflection history prior to Mach reflection) to prediction of triple-point loci of shock waves which undergo surface reflection prior to Mach reflection.

C6. Gamma-Ray Collimator Penetration Effects. R. L. MATHER, *U. S. Naval Radiological Defense Laboratory.*—Theoretical calculations have been made of the effective opening for the passage of radiation through a cylindrical hole in a slab of material as a function of the angle between the direction of the radiation and the axis of the hole. The contributions to this aperture from the unimpeded, "geometrical" opening and from penetration of the collimator edges are calculated separately. The numerical results are presented graphically. When integrated over all directions, a penetration aperture nearly equal to the geometrical aperture is possible in some practical collimators. Penetration effects, to a first approximation, are equivalent to removing one mean-free-path of material from each side of the collimator slab.

C7. Gamma-Ray Penetration of Collimators. C. SHARP COOK, *U. S. Naval Radiological Defense Laboratory.*—The radiation from a point source of gamma radiation in passing through a cylindrically shaped collimator will not be defined exclusively by the geometrical aperture of the collimator. Some of the radiation will penetrate the edges of the collimator. Calculations of the magnitude of this penetration have been made for a ½-inch diameter cyclindrical aperture in a lead collimator from point sources, located on the axis of the cylindrical aperture, 8, 16, and 32 inches from the detector end of the collimator. From these calculations it is possible to determine the excess area expected in the full energy peak of a pulse-height spectrum from a NaI(Tl) crystal spectrometer. The ratio of all counts recorded in the full energy peak to those defined by the geometrical aperture are listed in Table I.

TABLE I.

Gamma energy (Mev)	Absorption coef. (cm^{-1})	Source distance (inches) 8	16	32
0.662	1.215	1.09	1.04	1.02
1.23	0.660	1.20	1.08	1.04
2.76	0.457	1.40	1.13	1.06

C8. Experimental Gamma-Ray Collimator Sensitivity Patterns. F. M. TOMNOVEC AND R. L. MATHER, *U. S. Naval Radiological Defense Laboratory.*—The spatial sensitivity pattern of a gamma-ray collimator and NaI scintillation detector was explored with small radiation sources of three gamma-ray energies (0.145 Mev, 1.12 Mev, 1.59 Mev). The collimator used was a cylindrical hole of ½-inch diameter through 8 inches of lead. The results are compared with calculated patterns based on the theoretical calculations of R. L. Mather. The effects of penetration of the collimator edges are clearly shown.

C9. Scattered Radiation Received by a Noncollimated Receiver from a 4π Source. MATHEW G. GIBBONS, *U. S. Naval Radiological Defense Laboratory.*—The relative amounts of scattered and direct visible radiation received from a 4π point source by an uncollimated receiver have been computed for receiver acceptance angles from 0 to 180° and for various optical thicknesses and scattering functions. A uniform infinite atmosphere has been assumed, and only single scattering has been taken into account. Three simple but representative phase functions have been used in the calculations, namely, $1+\cos^{16}(\phi/2)$, $1+9\cos^{16}(\phi/2)$, and $1+50\cos^{64}(\phi/2)$, where ϕ is the scattering angle measured from the forward direction of the radiation. The ranges of optical thickness for which calculations have been made with these phase functions are 0.033–1.2, 0.1–3.6, and 0.3–10.8, respectively. For optical thicknesses less than about 0.5, fair agreement has been found between the calculated results for the phase function $1+9\cos^{16}(\phi/2)$ and those given by the semi-empirical formula of Stewart and Curcio.[1] However, at larger optical thicknesses the latter formula predicts a much greater scattered-in contribution than is given by the straightforward calculation, the difference increasing with increasing optical thickness.

[1] H. S. Stewart and J. A. Curcio, J. Opt. Soc. Am. 42, 801 (1952).

THURSDAY AFTERNOON AT 2:30

Spanagel 400

(S. D. DRELL presiding)

Invited Papers

D1. Relaxation Theory. FELIX BLOCH, *Stanford University.* (30 min.)

D2. Plasmons, Phonons, and Demons. DAVID PINES, *Princeton University.* (30 min.)

D3. Penetration of Heavy Charged Particles in Matter. EDWIN A. UEHLING, *University of Washington.* (30 min.)

D4. Collective Interactions in Many-Particle Quantum Mechanical Systems. KENNETH M. WATSON, *University of Wisconsin.* (30 min.)

THURSDAY AFTERNOON AT 1:30

King Hall

(N. L. OLESEN presiding)

Invited Papers Sponsored by the Division of Electron Physics

E1. Sputtering at Low Ion Energies. G. K. WEHNER, *General Mills, Inc.* (30 min.)

E2. Plasma Electron Oscillation. K. G. EMELEUS, *Queen's University, Belfast, Ireland.* (40 min.)

E3. Ionization of the Hydrogen Atom on Electron Impact. W. L. FITE, *General Atomics.* (30 min.)

E4. The Role of the Positive Streamer in Filamentary Spark Breakdown. L. B. LOEB, *University of California, Berkeley.* (30 min.)

E5. Absorption Studies of Metastable Atoms and Molecules. A. V. PHELPS, *Westinghouse Research Laboratory.* (30 min.)

THURSDAY AFTERNOON AT 1:00

Spanagel 421

(R. P. JOHNSON presiding)

Solid State I

F1. Equipment for Observing Shear Modulus of Copper under Irradiation. D. A. POWELL, H. S. SELLERS, E. A. MILNE, AND E. C. CRITTENDEN, JR., *U. S. Naval Postgraduate School.*—In order to observe the change in shear modulus, G, of copper under electron bombardment and its recovery with thermal pulse annealing, a 1¼-inch specimen of 10-mil copper wire was mounted as the torsion element of a 17-gram torsional pendulum. The wire was drawn from 99.999% pure Johnson-Mathey ¼-in. bar and annealed for 15 minutes at 950°C, resulting in large grain size comparable to the wire diameter and oriented with [111] direction within 11° of wire axis. The pendulum was suspended in a tank at the end of the accelerator tube of a horizontal 2-Mev Van de Graaff and was maintained in a helium atmosphere near liquid nitrogen temperature throughout irradiation and measurement. A "galvanometer type" optical system for observing the period, an electric furnace for annealing, and thermocouples for monitoring the temperature of the specimen were all provided, such that all irradiation, annealing, and measurements could be performed without disturbing the specimen. The electron beam was distributed linearly along the full length of the specimen by periodic deflection. G was observed through the pendulum period (reproducible within 5 parts in ten thousand by timing 100 oscillations). Pendulum deflection was kept below critical shear stress and pre-irradiation cold work was varied from absolute minimum up to one full turn twist in different specimens.

F2. Effects of Electron Irradiation on the Shear Modulus and Internal Friction of Copper. H. S. SELLERS, D. A. POWELL, E. C. CRITTENDEN, JR., AND E. A. MILNE, *U. S. Naval Postgraduate School.*—The shear modulus, G, of copper under irradiation at −195°C by 2-Mev electrons, and its recovery with thermal pulse annealing, were observed using 1¼-in. long, 10-mil wire specimens containing controlled amounts of pre-irradiation cold work. In all cases G, as a function of integrated electron flux, increased during irradiation in roughly an exponential manner up to a constant value, reached after a 1% increase in the case of absolute minimum cold work, a 10% increase for 190° twist, and a 14% increase for one full turn. Total integrated flux per specimen ranged between 2.7×10^{18} and 5.3×10^{18} electrons per cm². Percentage increases were based on final constant values of G which were the same within 4% for all specimens, the pre-irradiation values varying with the amount of cold work. Similar decreases in internal friction were noted simultaneously. Following irradiation, specimens were thermally annealed from −195°C up to +300°C for 15 minutes at each increment of 25°. In all cases G and internal friction remained approximately constant during annealing. Two cold-worked specimens carried to +450°C showed slight linear recovery (less than 20% of original increase) commencing around 250°C. The behavior fits a model employing stable pinning of dislocations by the point defects created during irradiation.

F3. The Color, Luminescence, and Paramagnetism Induced in Some Organic Compounds by Irradiation. T. H. ANDERSON AND R. S. ALGER, *U. S. Naval Radiological Defense Laboratory.*—As previously reported,[1] several simple alcohols become colored upon irradiation at low temperatures. Further attempts to measure a photoconductivity during bleaching were unsuccessful, indicating that the color is not due to trapped electrons. Moreover, the paramagnetic resonance spectrum shows the presence of free radicals which are stable to visible light after the color centers have been completely bleached. Ketonic compounds develop thermoluminescence and paramagnetism under irradiation, both of which can be removed by exposure to light. As the temperature is raised, the free radicals sharply decrease near the temperature of the maximum of the glow curve, indicating that the thermoluminescence is activated by a free radical mechanism. The decay of luminescence at constant temperature follows a power law relation indicating that the rate controlling step is a diffusion process.

[1] Anderson, Jordan, and Alger, Phys. Rev. **100**, 964(A) (1955).

F4. Saturation and Yield of Free Radicals by Irradiation. R. S. ALGER, J. B. DRAHMANN, AND T. H. ANDERSON, *U. S.*

Naval Radiological Defense Laboratory.—Measurements of the average energy expended in producing an unpaired electron were made using irradiated solid methanol, ethanol, and acetone. As the concentration of radicals builds up under irradiation, the apparent efficiency of production decreases as a saturation condition is approached. Samples of the organic materials maintained at liquid nitrogen temperature were bombarded in an evacuated Faraday cup with 2-Mev electrons and observed at 640 megacycles in an electron spin resonance spectrometer. In the energy determinations the 2-Mev electrons were completely stopped in the sample; therefore, the absorbed energy was considered to be the product of the number of electrons collected and the accelerating voltage. The number of spins produced were obtained from a comparison of the areas under absorption curves for irradiated samples against the area under curves for 1,1 diphenyl 2-picrylhydrazyl. The energy per spin observed was the order of 18, 12, and 64 ev for methanol, ethanol, and acetone, respectively. Concentrations of several times 10^{19} spins per cc were produced in acetone and methanol in the saturation region.

F5. Microscopic Effects Produced by Alpha Irradiation of Potassium Iodide. E. R. LEVIN, D. B. ROSENBLATT, AND E. L. OFFENBACHER, *Frankford Arsenal.*—Charged particle irradiations of the order of 10^{13} per cm^2 produce visible coloration and anomalous birefringence in alkali halides.[1] Reduction of the integrated flux to approximately 10^6 per cm^2 should produce regions of damage sufficiently dispersed to allow microscopic observation of individual events. The effects of such low-level irradiations were studied in cleaved single crystals of potassium iodide bombarded with uranium alpha particles. A polarizing microscope revealed birefringent regions in the irradiated specimens. While most of the regions appear as mere points of light against a dark background, some short lines, similar to tracks in photographic emulsions, are observed. Maximum lengths agree approximately with calculated ranges of the particles in potassium iodide, and the number of events per unit area is in order of magnitude agreement with the integrated alpha flux. No fading of the effects as a result of exposure to ordinary light and room temperature has been observed. These experiments will be compared with previously reported microscopic observations of irradiated alkali halides.[2] Physical and chemical changes which may give rise to such effects will be discussed.

[1] Primak, Delbecq, and Yuster, Phys. Rev. **98**, 1708 (1955).
[2] L. Wieninger and N. Adler, Acta Phys. Austriaca **IV/1**, 81 (1950).

F6. Annealing of Electron Bombardment Damage in Single Silicon Crystals. G. BEMSKI AND W. M. AUGUSTYNIAK, *Bell Telephone Laboratories, Inc.*—Single silicon crystals of n and p type have been irradiated with a monoenergetic electron beam of 0.7-Mev energy from a van de Graaff accelerator. Changes in lifetime of minority carriers have been measured, and annealing has been performed between 230°C and 400°C. An almost complete recovery of lifetime is attributed to annealing of introduced vacancies and interstitials. Activation energy for this process of about 1.1 ev has been obtained. The rate of annealing is not the same in all crystals, indicating that imperfections present in the crystal as grown play a role in this process. Kinetics of annealing vary from monomolecular to bimolecular type, pointing also to the influence of originally present imperfections.

F7. Localized Radiation Damage as a Source for Interstitials or Vacancies. W. SHOCKLEY AND R. N. NOYCE, *Shockley Semiconductor Laboratory.*—One of the chief obstacles in studying vacancies and interstitials in homopolar crystals and metals is the lack of suitable sources for them. An important possible source is spatially localized radiation damage in the presence of sinks which are preferentially for one type. Bombardment of a surface with argon ions at one ampere per square cm may introduce $S=6\times10^{18}$ cm^{-2} sec^{-1} vacancy-interstitial pairs within a few, say A_v and A_i, lattice constants of the surface. If the surface is a perfect sink and another sink, such as a tilt boundary, lies at A_b, then the matter flow to the sink will be $\sim(A_i-A_v)S/A_B$. A fifty-hour bombardment of a half degree Washburn-Parker boundary in a specimen 10^{-2} cm thick should produce a six-minute angle change and additional severe inhomogeneous strains. S may be large compared to detailed-balanced equilibrium vacancy flux to surface which is $\sim D_{self}/(\text{atomic volume})^{4/3}\cong4\times10^{-14}$ for Ge at 800°C. Another type of unbalanced vacancy-interstitial source will probably result from "filtering" electron beam radiation damage through small angle grain boundaries. The recently developed copper precipitation technique of Dash for dislocations in silicon may be used to detect matter flow through distortion of dislocation patterns.

FRIDAY MORNING AT 9:00

King Hall

(F. BOEHM presiding)

Invited Papers

G1. Progress toward a Unified Theory of Nuclear Structure. S. A. MOSZKOWSKI, *University of California, Los Angeles.* (30 min.)

G2. The Spins and Magnetic Moments of Rubidium. J. C. HUBBS, *Radiation Laboratory, University of California, Berkeley.* (30 min.)

G3. Radioactivity of the Neutron Deficient Rubidium Isotopes. A. C. HELMHOLZ, *University of California, Berkeley.* (30 min.)

G4. Some Trends in Research on Nuclear Structure. M. GOLDHABER, *Brookhaven National Laboratory.* (30 min.)

G5. New Nuclear Reactions Initiated by 2-Mev Lithium Ions. S. K. ALLISON, *Enrico Fermi Institute for Nuclear Studies, University of Chicago.* (30 min.)

FRIDAY MORNING AT 9:00

Spanagel 400

(D. B. LANGMUIR presiding)

Solid State II

H1. Band Structure of Aluminum. V. HEINE,* *University of Cambridge* (introduced by C. Kittel).—Two attempts have been made to elucidate the band structure of aluminum, the one being through the interpretation of experimental results and the other a purely theoretical band structure calculation. In the first case some de Haas-van Alphen effect, anomalous skin effect, and electronic specific heat measurements have been used. The first two give information which is simply related to the shape of the Fermi surface, and the work has shown the power of using such data, although in the present case they were very incomplete. In this connection a theoretical study is now being conducted of what useful results might be obtainable from cyclotron resonance measurements in metals. In the theoretical approach, a band structure calculation with a self-consistent potential has been carried out for the first time. The potential has been based on an intuitive grafting of the Bohm and Pines theory of a free electron gas onto the Hartree-Fock equations, because at present there is no fundamental theory for taking electron correlation into account in a real metal.

* At present at the University of California, Berkeley, California.

H2. Effect of Heat Treatment on the Infrared Absorption of Silicon.* S. R. LEDERHANDLER, *Raytheon Manufacturing Company* (introduced by P. P. Debye).—If a specimen of silicon from a pulled rotated crystal is elevated to 1000°C, allowed to remain at this temperature for 48 hours, and then quenched to room temperature, a marked decrease in absorption occurs at 9.1 microns. Heat treatment of rotated specimens at 825°C, 645°C, and 470°C for a period of 48 hours indicates a progressively smaller reduction in the 9.1-micron band and finally no reduction at 470°C. Heat treatment at 1150°C and 1300°C following a 1000°C heat treatment restores the band, but it never becomes as high as the control nonheat-treated specimen. Such cycling of the band indicates that oxygen in the specimen moves from an optically inactive to an optically active site. Diffusion out of the specimen is of minor importance due to sample thickness. A band at 19.5 microns has also been found to decrease in amplitude following a 1000°C heat treatment. Pulled nonrotated crystals originally have a smaller 9.1-micron band than those grown by rotation. Heat treatment at 1000°C reduces this band to the same amplitude as observed in rotated heat-treated specimens. Heat treatment of nonrotated specimens at 470°C does not appear to increase the infrared absorption due to free carriers as observed in heat-treated rotated specimens.

* Supported in part by the Bureau of Ships, Signal Corps, U. S. Air Force.

H3. Sensitivity of Electrochemical Potential to Degree of Sintering.* BENNETT BOVARNICK, *Watertown Arsenal.*—An investigation of the sensitivity of the electrochemical potential of sintered iron powder to the degree of sintering is described. A system of independent powder particles has maximum energy content prior to solidification. As the system sinters to physically bounded particles, the energy of the system reduces. The energy change of the system should be measurable, according to Gibbs-Helmholtz, as electrochemical potential change. Carbonyl iron powder specimens, pressed to densities from 5.0 to 6.5 g/cc, were sintered at temperatures from 800°C to 1200°C for times to eight hours, constituting forty treatments for study. The test system included a reversible electrochemical cell as the sensing device with the output read through a null-balancing circuit. During the tests, the electrolytic cell was maintained under deoxidized nitrogen, required to retard the transition of ferrous ions to ferric ions. A saturated calomel half-cell made with contact with the $FeCl_2$ electrolyte through saturated KCl. Unsintered specimens exhibited an electrochemical potential of 724 mv, independent of packing density. The sintered specimens have potentials decreasing uniformly from the maximum for lightly sintered to 630 mv for severely sintered specimens.

* Supported by Ordnance Corps; taken from dissertation submitted to Boston University (February, 1956).

H4. Semiconducting Properties of ZnO. A. R. HUTSON, *Bell Telephone Laboratories, Incorporated.*—The Hall coefficient and electrical conductivity have been measured on *n*-type doped single-crystal specimens of ZnO between 55°K and 300°K. Doping was accomplished by interstitial diffusion of H, Zn, and Li at high temperature followed by a rapid quench.[1] Each of these additives gives rise to a Coulomb-type donor center. Analyses of the temperature dependence of the carrier concentration for samples with $N_D = 10^{16}$ to 10^{18} cm^{-3} yielded the following information: The donor ionization energy for these Coulomb centers in ZnO is 0.051 ev for $N_D = 1$ to 5×10^{16}, falling to 0.048 ev at $N_D = 10^{17}$ and becoming rather smeared out at $N_D = 10^{18}$. The quantity $(m^*/m)^{3/2}D^{-1} = 0.19$, where m^* is the "density-of-state" effective mass and D is the donor degeneracy and is independent of the additive and its concentration. Lithium introduces a small number of compensating acceptor sites, presumably due to an exchange between interstitial and substitutional positions. Hall mobility has been analyzed in terms of lattice scattering, ionized impurity scattering, and neutral impurity scattering. For relatively pure samples, $\mu_H(300°K) = 180$ cm^2 volt^{-1} sec^{-1} and $\mu_H(60°K) = 1400$ cm^2 volt^{-1} sec^{-1}.

[1] The doping procedures were devised by D. G. Thomas and J. J. Lander of Bell Laboratories, J. Chem. Phys. (to be published) and Bull. Am. Phys. Soc. Ser. II, 1, 348 (1956).

H5. Resistivity of Metals in Pauling's Valency Bond Theory of Metals. FELIX GUTMANN, *The N. S. W. University of Technology, Sydney, Australia.**—Metallic resistivity is treated on the basis of Pauling's theory. A transcendental, implicit equation is obtained for the relative resistivity r and solved numerically for Cu, using the published values for the bond energy E and the lattice coordination number γ. Good agreement is obtained over a range of temperature from 500 to 1300°K. While the conventional linear r *vs* temperature T relation is seen to follow as an approximation, it does not permit calculation of E. By means of a series development the following zeroth approximation is obtained: $r = K \exp -(E/RT\gamma)^{\frac{1}{2}}$, where K is a constant and R the gas constant. This equation agrees with the experimental data at least as well as the linear law over wide ranges of T. The values of E calculated therefrom agree with those derived from other measurements for all simple monovalant metals. A characteristic temperature is calculated which equals approximately the values of the Debye characteristic temperature. It is shown that the normalized temperature coefficient of resistance at the characteristic temperature is numerically equal to the reciprocal of that temperature, conforming to the Bridgman relation and to experimental results.

* Present address: Chemistry Department, The University of Southern California, Los Angeles, California.

H6. Thermal Diffusivity of Metals at Elevated Temperatures. EDWARD C. Y. INN AND C. P. BUTLER, *U. S. Naval Radiological Defense Laboratory.*—A new technique for the measurement of thermal diffusivity of metals at elevated temperatures will be described. The method is based on the one-dimensional heat-conduction problem of an insulated infinite slab of thickness, 1, with constant uniform irradiance Q cal cm^{-2} sec^{-1} on the face at $x=1$, i.e.,

$$\kappa \frac{\partial^2 V}{\partial x^2} = \frac{\partial V}{\partial t},$$

with $V=V_0$, a constant at $t=0$ and with boundary conditions at $x=0$ and $x=1$, $(\partial V/\partial x)=0$, $K(\partial V/\partial x)=Q$, respectively, where κ is thermal diffusivity, V the temperature, and K the the thermal conductivity. κ is defined as $K/\rho c$, where ρ is the density and c the specific heat. From the solution of this boundary value problem it is then possible to calculate K for different ranges in temperatures and also, under special conditions, K and c may also be determined. The experimental method thus consists of irradiating with a very intense light source one face of an insulated cylindrical metal specimen and measuring the temperature at one or several points along the latter as a function of time. Details of the technique will be described and the results of some preliminary measurements will be presented.

H7. Photoconductivity in Type IIb Diamond.* M. D. BELL† AND W. J. LEIVO, *Oklahoma A. and M. College.*—The photoconductivity of two specimens of semiconducting diamond[1] has been studied. The diamonds are photoconducting in the visible and near infrared with a major peak occurring at 660 mμ and a slight peak at 890 mμ. The photoconductivity is obtained without previous irradiation with ultraviolet light. Maxima of photoconductivity in the ultraviolet occur at 223 mμ and 228 mμ. The peak at 223 mμ was not observed in all parts of the diamonds. Also, the portion of one specimen which had the highest dark conductivity had no detectable photoconductivity in the ultraviolet above 190 mμ, the lower limit measured, but it did show the visible and near infrared photoconductivity. The photoconductivity was also dependent upon the direction of current flow through the crystal.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.

† Now with Phillips Petroleum Company.

[1] J. F. H. Custers, Physica **10**, 439 (1952); **20**, 183 (1954).

H8. Neutron Diffraction Study of the Magnetic Structure for the Perovskite-Type Mixed Oxides $La(Mn,Cr)O_3$.* U. H. BENTS, *Oak Ridge National Laboratory and the Agricultural and Mechanical College of Texas.*—The techniques of neutron diffraction which had been applied by Wollan and Koehler[1] to the study of magnetic structure properties of the perovskite-type mixed oxide system $(La,Ca)MnO_3$ have been applied to the similar system $La(Mn,Cr)O_3$. The antiferromagnetic layer type structure of the pure $LaMnO_3$ compound is rapidly destroyed and disappears with about ten percent chromium content. The antiferromagnetic structure of $LaCrO_3$, though diluted, persists over the large range of 0 to 70% manganese in the $La(Mn,Cr)O_3$ system. For compositions containing 10 to 50% chromium, an appreciable ferromagnetic moment is observed, the data indicating that about half of the atoms cooperate in the ferromagnetic scattering. For compositions with about 10 to 70% chromium, superlattice lines calling for a large magnetic cell are evident. The presence of this structure is correlated with appearance of ferromagnetism. Complementary saturation measurement data were obtained to verify the observed ferromagnetic moment. A magnetic field study of the superlattice line showed it to be field dependent. Hence it was evident that the supplementary structure for the intermediate compositions was ferrimagnetic.

* The research was performed at the Oak Ridge National Laboratory under the Oak Ridge Institute of Nuclear Studies Fellowship program.

[1] E. O. Wollan and W. C. Koehler, Phys. Rev. **100**, 545 (1955).

H9. Carrier Generation and Recombination in the Space-Charge Region of a p-n Junction. R. N. NOYCE, C-T. SAH, AND W. SHOCKLEY, *Shockley Semiconductor Laboratory.*—The current J_{sc} due to Shockley-Read[1] recombination centers in the space charge region is found to dominate the diffusion current J_D in some cases, both for reverse bias and for low forward bias. For reverse bias, J_{sc} is proportional to the space charge layer width. If J_{sc} is dominant, $(\tau_{n0}\tau_{p0})^{\frac{1}{2}}$ and E_t (Shockley-Read notation) may be determined from the magnitude and thermal activation energy of the reverse current. For forward bias J_{sc} is proportional to $\exp(qV/bkT)$ where $1<b<2$. Therefore, J_D/J_{sc} increases exponentially, so that at high forward bias $J_D>J_{sc}$. This may explain the variation of alpha of silicon transistors on the basis of measurable recombination center parameters. As an example, if the recombination centers lie close to the center of the gap and have approximately equal cross sections for holes and electrons, then $J_{sc}/J_D \doteq (m/n_i)(\tau_r/\tau)^{\frac{1}{2}}$, where m and n_i are the majority and intrinsic carrier densities, $\tau_r \equiv \rho\epsilon \equiv$ the dielectric relaxation time, and τ the minority carrier lifetime. This ratio is large for typical examples in silicon and for germanium at low temperatures.

[1] W. Shockley and W. T. Read, Jr., Phys. Rev. **87**, 835 (1952).

H10. Interpretation of Silicon p-n Junction Current-Voltage Characteristics. C-T. SAH AND W. SHOCKLEY, *Shockley Semiconductor Laboratory.*—The current-voltage characteristic of a junction made by diffusing aluminum into n-type silicon has been measured down to 0.10 volt. Extrapolating the currents to $\pm kT/e$ leads to a rectification ratio of about 2 suggesting that the same mechanism is involved in both forward and reverse currents. The reverse current shows an activation energy of 0.6 ev and varies with the width of the space-charge region, in agreement with previous findings.[1] The forward current varies as $\exp(eV/1.4kT)$ and has an activation energy of 0.7 ev. These findings are consistent with the theory of the preceding abstract. For large reverse bias the data may be well represented by integrating the ionization rates[2] over the space charge region.

[1] E. M. Pell and G. M. Roe, J. Appl. Phys. **27**, 768 (1956).
[2] K. G. McKay, Phys. Rev. **94**, 877 (1945).

H11. Diffusion Depths in Silicon Measured Using Cylindrical Grooves. W. W. HAPP AND W. SHOCKLEY, *Shockley Semiconductor Laboratory.*—Grooves of the order of 10 μ deep were machined into silicon surfaces using a cylinder rotating about its axis, with the axis at about 1° from the plane of the surface. Microscopic examination of the parabolic pattern thus obtained gives information on thickness and uniformity of (i) plated or deposited layers, (ii) impurity layers near the surface made visible by staining or differential etching, (iii) depths of surface damage due to lapping or etching. The advantage of this method over a plane bevel[1] is that the quadratic relationship between width and depth gives better resolution. For example, layer thicknesses of 3 to 12 microns have been measured with precision better than ±0.2 micron using a cylinder of 2-cm diameter. A conductance profile, obtained by probing the groove with a 5-micron diameter tungsten point, shows variations greater than 10^6; this determines the location of junctions in multi-layer diffusion-made structures. Similarly, photovoltaic response was used to identify p-n junctions. Anomolous layers obtained by staining Boron diffused p layers are tentatively explained. Photomicrographs of multi-layer structures will be shown and intepreted.

[1] C. S. Fuller and J. A. Ditzenberger, J. Appl. Phys. **27**, 543 (1956).

FRIDAY MORNING AT 9:30

Spanagel 421

(F. DE HOFFMANN presiding)

Theory

I1. Extensions of Equivalence Theorems.* M. A. RUDERMAN AND W. K. R. WATSON, *University of California, Berkeley.*—The equivalence theorems[1] which relate the lowest order matrix elements of direct couplings ($g\int\psi_2^+\gamma_5\boldsymbol{\varphi}\cdot\boldsymbol{\tau}\psi_1$ or $g\int\psi_2^+\boldsymbol{\varphi}\cdot\boldsymbol{\tau}\psi_1$) to those of the gradient couplings ($g'\int\psi_2^+\gamma_5\times\gamma_\mu\partial_\mu\boldsymbol{\varphi}\cdot\boldsymbol{\tau}\psi_1$ or $g'\int\psi_2^+\gamma_\mu\partial_\mu\boldsymbol{\varphi}\cdot\boldsymbol{\tau}\psi_1$) are shown to remain valid in the presence of certain families of radiative corrections. For example, the usual equivalences to lowest order in g and g' are unchanged by electromagnetic corrections to any order in e, or by the simultaneous inclusion of other interactions of the fermions with a neutral spinless boson field via gradient coupling and with a neutral spin one boson field via direct coupling. When both these other boson fields and the meson of the vertex carry charge, the extended equivalence holds only for particular combinations of matrix elements.

* Supported in part by the National Science Foundation.
[1] E.g., K. Case, Phys. Rev. **76**, 14 (1949).

I2. Series Solution for the Time-Dependent Schrödinger Equation.* F. R. HALPERN, *University of California, Berkeley.*—If the Hamiltonian operator H is a time-independent operator and the state $\psi_0(t_0)((\psi(t_0/\psi(t_0))=1)$ is the prescribed initial state, then the Schrödinger equation can be solved in terms of the state $E_1\psi_1(t)=[H-(\psi_0(t)|H|\psi_0(t))]\psi_0(t)\exp\times\{i(\psi_0(t)|H|\psi_0(t))t\}$. In general $\psi_1(t)$ will be unknown; however, it will also satisfy an equation of the Schrödinger type, and the process may be iterated leading to a series solution for $\psi_0(t)$. Each term in the series is a time-independent state vector multiplied by a function of the time. The convergence of the series can be discussed entirely in terms of the quantities $H_n=(\psi_0(t)|H_n|\psi_0(t))$, which are independent of the time. There are three cases: (1) $H_n\leqslant A^n$ for some A; in this case the series always converges. (2) $A^n<H_n<\infty$ for any A; in this case the series may diverge for some values of the time, but it appears that there are arbitrarily large values of the time for which it converges. (3) $H_n=\infty$ for some n; in this case the series fails to exist.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

I3. Proton Compton Effect.* W. K. R. WATSON, *University of California,* AND F. ZACHARIASEN AND W. J. KARZAS, *Rand Corporation.*—Within the framework of the Chew-Low-Wick development[1,2] an analysis of the scattering of photons from a nucleon is made. It is shown that an exact relation exists between the Compton effect amplitude and the experimental meson nucleon scattering phase shifts for all multipoles except magnetic dipole and electric quadrupole. That part of the magnetic dipole scattering which can be described in terms of the anomolous magnetic moments of the nucleon is also treated exactly. Those parts of the effect not included in the above are handled in the one meson approximation. Preliminary calculations indicate a resonance in the cross section at a photon energy about 300 Mev. No experimental evidence at this energy is as yet available.

* Supported in part by a National Science Foundation grant.
[1] G. F. Chew and F. E. Low, Phys. Rev. **101**, 1570 (1956).
[2] G. C. Wick, Revs. Modern Phys. **27**, 339 (1955).

I4. Center-of-Mass Motion in Many-Particle Systems. S. GARTENHAUS AND C. L. SCHWARTZ, *Stanford University.*—A unitary transformation, which projects out of any many-particle wave function its translationally invariant part, has been obtained. Explicitly, the transformation is

$$U=\exp\{-i\Lambda(\mathbf{P}\cdot\mathbf{R}+\mathbf{R}\cdot\mathbf{P})\},$$

where $\mathbf{P}$ is the operator for the total momentum, $\mathbf{R}$ is the operator for the center of mass, and Λ is a number which is eventually allowed to become infinite. This transformation has the property of leaving unaltered all internal symmetry properties of the system, and the transformed wave function is an improvement over the old one at least in a Rayleigh-Ritz variational sense in that the energy of the ground state is lower. In coordinate space, the transformed state can be obtained by referring all the particle coordinates to $\mathbf{R}$. Using this transformation, the problem of many particles coupled together in pairs by springs can be solved exactly in terms of independent particle functions, and the problem of the "spurious states"[1] can thus be handled.

[1] J. P. Elliot and T. H. R. Skyrme, Proc. Roy. Soc. (London) **A232** (1955).

I5. Recoil Corrections to Nuclear Moments. C. L. SCHWARTZ AND S. GARTENHAUS, *Stanford University.*—The center-of-mass operator described in the preceding abstract has been used to construct operators for the electromagnetic multipole moments of nuclei which include recoil effects. These new operators are obtained from the usual ones by the replacements

$$\mathbf{r}_i\rightarrow\mathbf{r}_i-\Sigma_j\mathbf{r}_j/A\,;\quad \mathbf{p}_i\rightarrow\mathbf{p}_i-\Sigma_j\mathbf{p}_j/A.$$

The change in these operators cannot be represented simply as giving an effective charge to each nucleon since there are in general terms involving simultaneously the coordinates of two or more particles. These recoil corrections have been evaluated in the harmonic oscillator shell model, and it is found that the net recoil correction for the $E2$ moments is zero. Thus the quadrupole moment and $E2$ transition rate measured in O^{17} must be due entirely to configuration mixing (core excitation). Results of calculations for $M1$ moments will also be given.

I6. Polarization of High-Energy Nucleons Scattered by Carbon.* K. NISHIMURA AND M. RUDERMAN, *University of California, Berkeley.*—Analyses of the polarization of elastically scattered 289-Mev protons from carbon[1] show that it is difficult to understand the observed polarization[2] even when a large variety of well shapes and parameters are introduced. We have calculated contributions from almost elastic scattering (mostly excitation of the 4.3-Mev level) on the assumption that those low-lying energy levels that are strongly excited can be considered a collective excitation. Then in Born approximation the polarization is exactly the same as for elastic scattering,[3] but more precise calculations show important differences. Superposition of the results for elastic and almost elastic scattering with partial cross sections inferred from electron scattering and from 96-Mev nucleon scattering gives good qualitative fits to observed polarization.[2,4]

* Work supported in part by National Science Foundation.
[1] Fernbach, Heckrotte, and Lepore, Phys. Rev. **97**, 1059 (1955).
[2] Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **102**, 1659 (1956).
[3] M. Ruderman, Phys. Rev. **98**, 267 (1955).
[4] Chestnut, Hafner, and Roberts, submitted to *The Physical Review.*

I7. Chew-Low Formalism for Two Interactions.* S. D. DRELL, *Stanford University,* AND F. ZACHARIASEN, *University of California, Berkeley.*—An extension of the method of Chew and Low is developed for interacting boson-fermion systems for which a portion H_1 of the interaction can be treated exactly

and is included in the zero order problem. The remaining contribution to the scattering is expressed as the solution of a Chew-Low type equation in which the inhomogeneous term involves eigenstates of H_0+H_1 instead of H_0. This method is applied to the scalar pair term of meson theory.

* Work supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.

I8. Λ^0 Nucleon Force. E. M. HENLEY, *University of Washington.*—A study of the Λ^0 nucleon force is of particular interest because the two-body interaction is not necessarily intimately related to the force between the Λ^0 and two or more nucleons, as deduced from bound hyperfragments. Thus, an exchange of a single pion between the Λ^0 and the nucleon is forbidden only in the two-body interaction, but not when more nucleons are present. This is not true for any other known hyperon. Furthermore, whereas the nature of the Σ^0 nucleon interaction can be studied experimentally by scattering measurements and the use of isotopic spin independence, no such techniques are available for the Λ^0 nucleon force. This force, however, can be measured close to the threshold for production of these particles and a K meson because the final state interaction modifies the spectrum of produced K mesons.[1] The results which may be expected on the basis of present knowledge will be discussed for nucleon-nucleon collisions at 1.75 Bev, just below the threshold for Σ production. Pion-deuteron collisions can also be used.

[1] K. M. Watson, Phys. Rev. **88**, 1163 (1952).

I9. Optical Model Analysis of Proton-Nucleus Scattering.* A. E. GLASSGOLD, W. B. CHESTON, S. SCHULDT, AND G. W. ERICKSON.—Optical model studies[1] at 10 Mev have been continued[2] and more precise fits obtained with Hintz's data.[3] More information is now available about the three important parameters at this energy, VR^2, a, W. The positions of maxima and minima are still largely determined by the value of VR^2, but certain restrictions can be made on the range of the radius parameter.[4] If $r_0=RA^{-1/3}$, a value of $r_0=1.20$ may be used for the cases where precise fits are possible. However, $r_0=1.33$ works just as well for certain nuclei but not for others. The values of a and W depend somewhat on the value of r_0. Thus a number of solutions exist at this energy and a range of parameters must be given for each nuclei. Extension of these results to higher energies will also be reported.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Glassgold, Cheston, Stein, Schuldt, and G. W. Erickson, Bull. Am. Phys. Soc. Ser. II, **1**, 339 (1956).
[2] The authors are indebted to the Sperry Rand Corporation for the use of their St. Paul computing facilities.
[3] S. W. Chen and N. M. Hintz, Bull. Am. Phys. Soc. Ser. II, **1**, 327 (1956).
[4] R marks the halfway point of the potential.

I10. Optical Model Interpretation of the Elastic Scattering of Alpha Particles.* G. IGO, *Stanford University*, AND R. M. THALER AND D. L. HILL, *Los Alamos Scientific Laboratory.*—An optical model for the nucleus of the form $(a+ib)/\{1+\exp(r-r_0)/d\}$ has been employed in this analysis. Data obtained at 40 Mev[1] as well as at other energies[2] has been analyzed. For ten elements ranging from C to Th, the following average values have been obtained: $a=40$ Mev, $b=12$ Mev, $r_0=[(1.30\pm0.02)A^{1/3}+(1.60\pm0.10)]\times10^{-13}$ cm, and $d=0.5\times10^{-13}$ cm. The sensitivity of the analysis to variations in the parameters will be discussed. The computer facilities at the Low Alamos Scientific Laboratory were used in this work.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Igo, Wegner, and Eisberg, Phys. **101**, 1508 (1956); Wegner, Eisberg, and Igo, *ibid.* **99**, 1044 (1955).
[2] Wall, Rees, and Ford, Phys. Rev. **97**, 1726 (1955); R. Ellis and L. Schecter, *ibid.* **101**, 636 (1956).

I11. Quaternion Physical Quantities. J. G. WINANS, *University of Wisconsin.*—A physical quantity defined as a combination of length, force, and time is a quaternion $Q=S+V$ where S is a scalar quantity and V is a vector quantity. S may be a real number. Most physical quantities have either S or V equal to zero. Examples of quaternions with vector part zero are: mass, pressure, work, and volume. Examples of quaternions with scalar part zero are: area, torque, coefficient, of friction, surface tension, shearing stress, small angle, and tangent of an angle. The latter have units such as cm/cm with numerator cm perpendicular to denominator cm. Two quaternions with scalar and vector parts both different from zero are $\sin\theta$ and $\cos\theta$. The vector part of $\sin\theta$ equals the negative of the vector part of $\cos\theta$. The relation $\sin^2\theta+\cos^2\theta=1$ leads to the conclusion that multiplication of scalar and vector quantities is not commutative and that $SV=-VS$.

I12. Propagation Potentials. F. W. WARBURTON, *University of Redlands.*—The potential energy of two charges e' and e is expanded in a power series in $1/c$ and the relative position, velocity and acceleration. With a single suitable choice of coefficients, the average negative gradient of this energy yields (a) the transverse electric field of the oscillating electric dipole, (b) the usual vector potential and induced electric field of a changing primary current, (c) a stable electron, and (d) a radial reduced force equivalent to the usual relativistic increase in mass, up to and including terms in $1/c^4$. It provides for the influence from e' (at speed c) to expend only a part of its potential energy as e gains a speed approaching c and to deliver the remaining potential energy while e decelerates. In (a) and (d), the propagation time $\tau=r/c$ is included in taking the partial gradient, following closely the classical procedure of taking the gradient of the retarded potential. In (b) the classical procedure of neglecting radiation is followed, the distance r (in the integration about the primary circuit) not being considered a function of the time τ. In (c) the parts of the electron are considered as rotating in a circle with constant spacing r.

FRIDAY AFTERNOON AT 2:00

King Hall

(E. C. CRITTENDEN, JR., presiding)

Invited Papers

J1. Recent Experiments on Nuclear Orientation at Low Temperatures. N. KURTI, *Clarendon Laboratory, Oxford University.* (30 min.)

J2. Recent Methods of Polarizing Nuclei in Paramagnetic Substances. G. FEHER, *Bell Telephone Laboratories.* (30 min.)

J3. The Nuclear Resonance in Normal and Superconducting Metals. W. D. KNIGHT, *University of California, Berkeley.* (30 min.)

J4. Proton Spin Relaxation in Gaseous and Liquid Hydrogen. M. BLOOM, *Kammerlingh Onnes Laboratory, University of Leiden, and University of British Columbia.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Spanagel 421

(W. M. POWELL presiding)

Mesons I

K1. K^- Interactions in Hydrogen.* F. T. SOLMITZ, L. W. ALVAREZ, H. BRADNER, P. FALK, J. D. GOW, A. H. ROSENFELD, AND R. D. TRIPP, *University of California, Berkeley.*—K^- mesons from the Bevatron were stopped in a 10-inch hydrogen bubble chamber. The following reactions were observed: $K^-+p\rightarrow\Sigma^-+\pi^+$ (51 cases); $\rightarrow\Sigma^++\pi^-(27)$; $\rightarrow\Sigma^0+\pi^0(14)$; $\rightarrow\Lambda^0+\pi^0(7)$; here Λ^0, Σ^0 indicates the charged decay modes $\Lambda^0\rightarrow\pi^-+p$; $\Sigma^0\rightarrow\gamma+\Lambda^0$, $\Lambda^0\rightarrow\pi^-+p$; the distinction between the Λ^0 and Σ^0 reactions is made on the basis of kinematics. There were 25 ± 10 K^- endings that gave no visible products. Three examples of the process $K^-+p\rightarrow\tilde{\theta}^0+n$, $\tilde{\theta}^0\rightarrow\pi^-+\pi^+$ were observed, at least one, possibly all, of these taking place in flight. There were nine K^- interactions in flight that led to visible hyperons ($4\Sigma^-$, $1\Sigma^+$, $1\Lambda^0$). Fourteen Σ^+ decay into π^++N and 14 into π^0+p; $48\Sigma^-$ decay into π^-+n, the remaining 7 Σ^- interact with protons (one in flight and six at the ends of their ranges). Two of the Σ^- interactions are identified as $\Sigma^-+p\rightarrow\Sigma^0+n$, two as $\Sigma^-+p\rightarrow\Lambda^0+n$, and three give no tracks in the chamber. The angular distribution of the $\Sigma^\pm$ decay products is somewhat anisotropic, suggesting a Σ spin $>\frac{1}{2}$; there was no significant forward-backward asymmetry, as suggested by the parity doublet scheme. The measured mean lives are $\tau_{\Sigma^-}=(1.86\pm0.26)\times10^{-10}$ sec, $\tau_{\Sigma^+}=(0.86\pm0.17)\times10^{-10}$ sec, $\tau_\Lambda=(3.25\pm0.60)\times10^{-10}$ sec; there was no evidence for more than one lifetime for any of these hyperons. Seventeen K^- mesons decayed in flight, four of them into three charged pions.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

K2. The K^0 Meson as a Particle Mixture.* RICHARD LANDER, WILLIAM B. FOWLER, AND WILSON M. POWELL, *University of California, Berkeley.*—Gell-Mann and Pais[1] have postulated the existence of a long-lived neutral K meson (θ_2^0) which should behave like a mixture of two states (θ^0 and $\tilde{\theta}^0$). Snow[2] has pointed out that τ_2^0 particles which are mixtures of τ^0 and $\bar{\tau}^0$ also probably exist. Lee and Yang[3] and Schwinger have discussed the role of parity and strangeness mixtures in the interactions of fundamental particles. Several experiments indicate the existence of a long-lived neutral K meson. This experiment is an attempt to obtain evidence that will enable one to determine the existence of the mixture of states and study its behavior. A beam of 1.25-Bev/cy π^- mesons was focused on a 4-by-4-by-12-in. Al producer. Neutral particles emitted from the producer at an angle of 5° with respect to the π^- beam traveled 9.3 ft to a propane bubble chamber, 3.25 in. deep by 6 in. wide by 12 in. long, operated in a 12-kilogauss magnetic field. A magnet swept charged particles from this beam. A total of 3.6×10^8 pions struck the Al producer. Preliminary analysis shows $7\Lambda^0$ hyperons and possibly $2\theta_1^0$ mesons in the chamber.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] M. Gell-Mann and A. Pais, Phys. Rev. **97**, 1387 (1955).
[2] G. Snow, Phys. Rev. **103**, 1111 (1956).
[3] T. D. Lee and C. N. Yang, Phys. Rev. **102**, 290 (1956).

K3. K^+ Production at Forward Angles by 6.2-Bev Protons on Copper.* L. VAN ROSSUM AND L. T. KERTH, *University of California, Berkeley.*—The characteristics of various 500-Mev/cy K^+ beams from the Bevatron have been investigated with emulsion stacks. Table I gives the estimated differential production cross sections per Cu nucleus for K^+ and the relative cross sections for π^+ and p^+. We include the corresponding figures for 90°. All data have been reduced, assuming a single mean life of 1.2×10^{-8} sec. The path length d from the target to the detector is given in column 7. Owing to uncertainties in the monitoring of the proton beam, the absolute cross sections may be in error by 70%. The errors given for $d\sigma_{\pi^+}/d\sigma_{K^+}$ and $d\sigma_{p^+}/d\sigma_{K^+}$ are standard deviations.

TABLE I.

Prod. angle	Av. prod. momentum (Mev/c)	$\frac{d\sigma_{K^+}}{d\omega dp}$ (microbarns / sterad × Mev/c)	$\frac{d\sigma_{K^+}}{d\omega d\Gamma}$ (microbarns / sterad × Mev)	$\left(\frac{d\sigma_{\pi^+}}{d\sigma_{K^+}}\right)_p$	$\left(\frac{d\sigma_{p^+}}{d\sigma_{K^+}}\right)_p$	d (cm)
0°	505	7.4	10	71 ± 21	28 ± 8	673
30°	520	3.4	4.7	34 ± 10	60 ± 18	691
60°	490	1.1	1.5	23 ± 7	87 ± 26	538
90°(1)	460	1.0	1.6	28 ± 11	300 ± 90	410

* This work was done under the auspices of the U. S. Atomic Energy Commission and supported in part by the National Academy of Sciences.

K4. Scattering of K^+ Mesons in a Propane Bubble Chamber.* DONALD I. MEYER, MARTIN L. PERL, AND D. A. GLASER, *University of Michigan.*—The scattering of positive K mesons in propane has been investigated using the University of Michigan's propane bubble chamber at the Brookhaven Cosmotron. The external proton beam of the Cosmotron hits a copper target producing a mixed beam of π and K mesons. This beam is sent through a double magnet system which improves the ratio of K mesons to π mesons entering the bubble chamber by a factor of about 50. The K mesons enter the chamber with an initial kinetic energy of 110 Mev and come to rest and decay in the chamber. The K mesons are identified by their decay products, bubble density, track scattering, and entrance position. Partial scanning of 20 000 pictures indicates that there are about 5000 K's which decay in the chamber. The ratio of τ mesons to all types of K mesons agrees with other results at the Cosmotron. The experimental arrangement will be described and preliminary results on the cross section for scattering by free protons will be given.

* Work supported by the U. S. Atomic Energy Commission.

K5. On the Spin of K Mesons from the Analysis of Antiproton Stars.* JACK SANDWEISS, *Radiation Laboratory, University of California, Berkeley,* AND MAURICE GOLDHABER, *Brookhaven National Laboratory.*—The antiproton-nucleon annihilation process has been shown to proceed primarily through pion production with occasional emission of K mesons.[1] The fraction P_K of stars yielding $K-\bar{K}$ pairs will depend upon the spin of the K mesons. We have used the Fermi statistical theory, threating the interaction volume as an adjustable parameter, to estimate the possible values of the K-meson spin (or spins) from the experimental value of P_K. We have neglected conservation of angular momentum and have assumed that the statistical weight for a pair of K mesons, each of spin I, is enhanced by a factor $(2I+1)^2$. The error caused by neglecting conservation of angular momentum has been studied and will be discussed. The momentum-space integrals have been performed by the "saddle-point" approximation method of Fialho. We find $I=0$ for the K meson most

likely but, with present data, cannot exclude higher spins. It has been shown[1] that, with the interaction volume chosen to fit the observed P_K and assuming spin-zero K mesons, the statistical theory predicts correctly the average number and energy spectrum of pions emitted in annihilation stars. Other tests of the theory have been devised and will be presented.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] *The Antiproton-Nucleon Annihilation Process* (*The Antiproton Collaboration Experiment*) (to be published).

K6. π^--Proton Interactions at 5 Bev.* GEORGE MAENCHEN, WILLIAM B. FOWLER, WILSON M. POWELL, AND ROBERT W. WRIGHT, *University of California, Berkeley.*—A 36-atmos hydrogen-filled diffusion cloud chamber operating in a pulsed magnetic field of 21 500 gauss has been exposed to 4.5- and 5.0-Bev/cy negative pion beams from the Bevatron. One hundred and thirty events which occurred in a well-defined region of the chamber have been analyzed. Of these, 24 are elastic scatters, 61 are inelastic collisions having two charged outgoing prongs, 37 have four charged outgoing prongs, 4 have six charged outgoing prongs, and 4 involve the production and visible decay of heavy unstable particles. Angular and momentum distributions, cross sections, and rough estimates of multiplicity of meson production will be given. Preliminary results of this study were presented in an earlier paper.[1]

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Maenchen, Powell, Saphir, and Wright, Phys. Rev. 99, 1619 (1955).

K7. Proton-Proton Interactions at 5.3 Bev.* ROBERT W. WRIGHT, WILSON M. POWELL, GEORGE MAENCHEN, AND WILLIAM B. FOWLER, *University of California, Berkeley.*—Approximately 100 events have been obtained by exposing a 36-atmosphere hydrogen-filled diffusion cloud chamber operating in a pulsed magnetic field of 21 500 gauss to a 5.3-Bev scattered proton beam from the Bevatron. In two of the events Λ^0 production and decay were observed. These events correspond to a cross section for Λ^0 production and charged decay in $p-p$ collisions at 5.3 Bev of about 0.5 mb. This is comparable to the cross section for heavy unstable-particle production in $\pi^- - p$ collisions at about the same available c.m. energy of 1.8 Bev[1] and indicates that these cross sections (for heavy unstable-particle production) are very probably of the same order of magnitude. This is in contrast with Brookhaven measurements at about half this available c.m. energy, which indicate a large difference between the p-nucleon and the $\pi^- - p$ cross sections for production of heavy unstable particles. Data will also be presented on the elastic cross section and angular distribution and the inelastic cross section and charged-particle multiplicities at 5.3 Bev. A preliminary report on part of the work appeared previously.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] See preceding abstract, "π^--proton interactions at 5 Bev," by Maenchen, Fowler, Powell, and Wright.

K8. Enriched K-Meson Beams from the Bevatron.* H. H. HECKMAN, F. W. INMAN, C. J. MASON, N. A. NICKOLS, F. M. SMITH, W. H. BARKAS, W. F. DUDZIAK, AND P. C. GILES, *University of California, Berkeley.*—In an effort to develop improved facilities for the exposure of emulsion to K mesons, we have employed a double magnetic bending method to produce beams of good intensity, separated from pions. Negative and positive particles emitted from the target at 0° and 180°, respectively, are deflected by the Bevatron magnetic field through 90° and emerge from the Bevatron along a radial line with momenta of about 430 Mev/c. By means of a quadrupole lens the particles are focused upon a polystyrene degrader in a beam about 2 in. in diameter. Upon traversing the degrader, the K-meson momentum is reduced to 300 Mev/c and the pion momentum to 393 Mev/c. On bending the K-meson beam through 180° it is possible to attain an essentially complete separation of the K and π mesons. The exposure time is limited, however, by the flux of μ mesons and electrons that arise from pion decays. We have obtained up to 50 K^- mesons/cm^2/10^{13} beam protons in a preliminary exposure of a 3-by-3-by-6-in. emulsion stack. The scanning efficiency for detecting the entering K particles is greater than 98%. We have found that the weakly interacting μ-meson background does not seriously interfere with our scanning procedures and that the random background is negligible.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

K9. Interaction and Decay of Negative K Mesons.* F. M. SMITH, W. H. BARKAS, W. F. DUDZIAK, P. C. GILES, H. H. HECKMAN, F. W. INMAN, C. J. MASON, AND N. A. NICKOLS, *University of California, Berkeley.*—A small emulsion stack exposed to evaluate the negative K-meson beam described in the previous abstract has not only provided beam information for later exposures but also has itself proved valuable for K-meson and hyperon research. More than 1000 tracks have been followed from the points where the K particles entered the emulsion to the points where they decayed or interacted. This work provides data for estimates of mean free paths for the various collision processes, particle masses, and the K-meson lifetime.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

K10. Hyperons and Hyperfragments from K^- Interactions in Emulsion.* F. W. INMAN, C. J. MASON, N. A. NICKOLS, F. M. SMITH, W. H. BARKAS, W. F. DUDZIAK, P. C. GILES, AND H. H. HECKMAN, *University of California, Berkeley.*—The negative K-meson study described in the previous abstract has yielded more than 1000 negative K-meson interactions. Some 25 charged hyperons and 31 hyperfragments associated with the interactions have been seen thus far. Analysis of these hyperon and hyperfragment events is now in progress. The emulsion density and shrinkage factor have been measured carefully so that with the new range-energy relation[1] precise Q values can be obtained.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] W. H. Barkas, UCRL-3384, April 9, 1956 (unpublished).

K11. Unusual Events Observed in a Multiplate Cloud Chamber.* N. F. HARMON,† M. ANNIS,‡ AND R. D. SARD, *Washington University.*—In the 3000 pictures obtained in the experiment described in the two preceding abstracts,[1] several unusual events have been found. These will be dsecribed and discussed.

* Supported by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission. and by a grant from the Research Corporation.
† Now at St. Mary's College, California.
‡ Now at Allied Research Associates, Inc., Boston, Massachusetts.
[1] N. F. Harmon, thesis, Washington University, St. Louis, 1955 (unpublished); Annis, Harmon, and Sard (to be published).

K12. Evidence for a $V^0 \rightarrow e + \pi$ Decay.* R. D. SARD, N. F. HARMON,† AND M. ANNIS,‡ *Washington University.*—In the multiplate cloud chamber experiment described in the preceding abstract, a V^0 event (opening angle (72±4)°) has been found in which one decay product appears to be an electron, the other a π meson. The former makes an electron shower of estimated energy (280±100) Mev in the first plate it strikes. The latter penetrates all eleven plates at minimum ionization without multiplying and has one large scattering (11°) that identifies it as strongly interacting. Multiple scattering gives $pv = (560 \pm 100)$ Mev. On the basis of ionization and range, it is

lighter than a proton. We take it to be a π meson. The foregoing energies and angle give $Q(\pi,e)=(350\pm100)$ Mev. A clean-cut case of $V^0\rightarrow\pi^++e^-(Q(\pi^+,e^-)=82$ Mev) has recently been found at the École Polytechnique,[1] and a V^0 event reported by Cowan[2] should probably be interpreted in this way ($Q(\pi^+,e^-)=225$ Mev). All the cases are compatible with $K_{\beta}^0\rightarrow e+\pi+\nu$. A possible alternative explanation of our event is as $\theta^0\rightarrow\pi+\pi$ followed by a charge-exchange, but the expected number of these in our sample is less than 6×10^{-3}.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by a grant from the Research Corporation.
† Now at St. Mary's College, California.
‡ Now at Allied Research Associates Inc., Boston, Massachusetts.
[1] L. Leprince-Ringuet, Rochester Conference, 1956.
[2] E. W. Cowan, Phys. Rev. **94**, 161 (1954).

FRIDAY AFTERNOON AT 1:30

Herrmann Hall, Copper Cup Room

(D. S. SAXON presiding)

Scattering

L1. Neutron Production from Thick Targets by Electron Bombardment.* W. D. GEORGE, *Stanford University.*—The production of neutrons by the bombardment of electrons upon thick targets was studied using target thicknesses from one to six radiation lengths. The data were taken as a function of the energy of the initial electron up to 35 Mev. For targets of one radiation length at an electron energy of 34 Mev, the following yields were obtained:

Target	Neutron per electron
Carbon	$1.53\pm0.01\ \times10^{-4}$
Concrete	$2.28\pm0.015\times10^{-4}$
Aluminum	$3.84\pm0.015\times10^{-4}$
Copper	$11.51\pm0.12\ \times10^{-4}$
Tantalum	$16.20\pm0.17\ \times10^{-4}$
Lead	$18.85\pm0.13\ \times10^{-4}$
Uranium	$42.00\pm0.22\ \times10^{-4}$
Uranium (3 rad. lengths)	$125.3\ \pm1.0\ \times10^{-4}$

The errors given are statistical only, giving indication of the accuracy of the relative yields. Absolute errors due to uncertainties in angular distribution and in counting efficiency are approximately 10%. Thin targets of heavy water and copper were used for calibration of equipment.

* The research reported here was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

L2. Electrodisintegration of Be^9.* W. C. BARBER, *Stanford University.*—The yield of neutrons from a "thin" beryllium target bombarded with a beam of monoenergetic electrons has been compared with the corresponding yield when a thin aluminum radiator is placed directly in front of the beryllium target. The experiment was performed using electrons of energy from 6 to 17 Mev produced by the Stanford Mark II accelerator. The yield from the beryllium alone is chiefly due to the reaction $Be^9(e,e',n)$ while the yield from the combination is due to this process as well as the reaction $Be^9(\gamma,n)$ caused by bremsstrahlung produced in the aluminum. After corrections for the effects of finite target and radiator thickness, the relative yields due to the electrons and their bremsstrahlung can be compared with the predictions of theory.[1] Agreement within experimental error of 3% is obtained if the transitions, Be^9 to Be^8+n, are electric dipole. Results of electrodisintegration experiments on other nuclei will also be discussed.

* The research reported here was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] E. Guth and C. J. Mullin, Phys. Rev. **76**, 234 (1949).

L3. Proton Bombardment of N^{14} below 650 kev.* J. C. OVERLEY, R. E. PIXLEY, AND W. WHALING, *California Institute of Technology.*—The reactions $N^{14}(p,p)N^{14}$ and $N^{14}(p,\gamma)O^{15}\rightarrow N^{15}+\beta^+$ have been studied in the energy range from 220 to 650 kev. The absolute cross section for elastically scattered protons is Rutherford below 400 kev except for a resonance at 278 kev. The data taken at 90, 129, and 150 degrees are consistent with $J=\frac{1}{2}^+$ level assignment and a level width of 1.6 kev for the 7.61-Mev level in O^{15}. Above 400 kev the scattering cross section rises above Rutherford. The reaction cross section from 220 to 350 kev is almost entirely due to the 278-kev resonance. Contributions to the reaction cross section from other resonances are seen above 350 kev. The thick target gamma-ray yield was measured at 310-kev bombarding energy. Data taken at 0 and 90 degrees show no anisotropy in the 0.75 and 1.35-Mev gamma rays, consistent with s-wave formation of the 7.61-Mev state in O^{15}.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

L4. Elastic Scattering of Protons by N^{15}.* F. B. HAGEDORN, *California Institute of Technology.*—The differential cross section for the elastic scattering of protons from N^{15} has been measured over the angular range of 75° to 160° and for proton energies between 650 and 1800 kev. Thin N^{15} targets were prepared by collecting the mass-30 beam from an electromagnetic isotope separator in graphite disks. Scattering cross section anomalies are observed at incident proton energies of 715, 898, 1010, 1210, and 1640 kev, corresponding to previously reported excited states in O^{16} in all cases except the first. An analysis of this scattering data has been made and leads to the assignment $J=0^-$ for the 715-kev state ($\Gamma=51\pm5$ kev). The assignments $J=2^-$ at 898 kev and $J=1^-$ at 1010 kev are consistent with both this and earlier work. The scattering data is well fitted with $J=3^-$ for the 1210-kev state but is inconsistent with $J=4^+$ as is suggested by the α_1 angular distribution.[1] A completely satisfactory description of the 1210-kev state has not yet been found. The scattering data at 1640 kev is consistent with $J=1^+$, thereby resolving the choice[2] between $J=1^+$ and $J=2^-$.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Kraus, French, Fowler, and Lauritsen, Phys. Rev. **89**, 299 (1953).
[2] A. A. Kraus, Jr., Phys. Rev. **94**, 975 (1954).

L5. Neutron Scattering from Spheroidal Nuclei.* J. L. URETSKY, *University of California, Berkeley.*—Scattering cross sections have been computed for zero energy neutrons incident upon a square well of spheroidal symmetry, depth 42 Mev, and volume equal to that of a sphere of radius 1.45×10^{-13} $A^{\frac{1}{3}}$ cm. For small distortions the resonance which, in the spherical case, occurs near mass number 150 at first shifts slowly in the direction of higher mass numbers and then splits. When the ratio of the interfocal distance to the major axis of the spheroid is 0.4, one finds resonances at mass numbers

of 135 and 160. The effect of including absorption is estimated by assuming that each resonance has the same shape as it would for a spherical well. The net effect upon the cross section is to give a very broad peaking over the rare earth region with a maximum near mass number 170.

* Research supported by the Office of Naval Research through the Physics Department and Digital Computer Laboratory at the Massachusetts Institute of Technology.

L6. Large-Angle Elastic Scattering of 14-Mev Neutrons off Iron.* CALVIN WONG, JOHN D. ANDERSON, CALVIN C. GARDNER, AND M. P. NAKADA, *University of California, Livermore.*—A time-of-flight method has been used to measure the elastic scattering of 14-Mev neutrons off iron in the angular range 130° to 160°. A 1-meter radius iron ring having 10-cm ×1.2-cm rectangular cross section was fixed in position at 90° to the tritium target. The neutron detector was a plastic scintillator biased at 11.4 Mev and movable along the axis of the ring to vary the scattering angle. A 12-in. copper rod placed between target and detector attenuated the direct neutrons. The method depends on the fact that neutrons transmitted through the copper and small-angle air elastic neutrons are time-separated from the iron elastic neutrons. For example, at 145° this time separation amounts to about 30 millimicroseconds, while the resolution of our time-of-flight equipment, as measured by the width of the elastic neutron peak, amounts to about 4 mμsec. The measured differential cross section (millibarns/steradian) varies smoothly from about 7 mb/sterad at 130° to about 10 mb/sterad at 160°. The probable errors from counting statistics alone vary between 10% and 15%. The angular resolution was roughly ±2°. The present results therefore show no sharp dip in the angular distribution at 155° as is predicted by the model by Bjorklund *et al.*[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Bjorklund, Fernbach, and Sherman, Phys. Rev. **101**, 1832 (1956).

L7. Inelastic Scattering of Alpha Particles from Li^7.* HOMER E. CONZETT AND ROBERT SILVER, *University of California, Berkeley.*—The 48-Mev alpha-particle beam of the Crocker Laboratory 60-inch cyclotron was directed at a thin lithium target located at the center of a 36-inch scattering chamber.[1] Energy spectra of scattered particles were obtained by pulse-height analysis of the output of a NaI scintillation counter, and from these spectra differential cross sections were determined for the inelastic scattering leading to the formation of the 4.61-Mev state of Li^7. The angular-distribution data extend from 11 deg to 112 deg in the center-of-mass system and exhibit a prominent peak near the forward direction. This maximum appears near 17 deg followed by a minimum near 30 deg, the relative cross sections being approximately 15 to 1. The magnitude and shape of the forward peaking indicates that a direct-interaction type of scattering[2] is predominant over any contribution from compound-nucleus formation and decay.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] R. E. Ellis and L. Schecter, Phys. Rev. **101**, 636 (1956).
[2] Austern, Butler, and McManus, Phys. Rev. **92**, 350 (1953); S. Hayakawa and S. Yoshida, Progr. Theoret. Phys. (Japan) **14**, 1 (1955).

L8. Nonelastic Cross Sections at 14.2-Mev Neutron Energy.* MALCOLM H. MACGREGOR, WILLIAM P. BALL, AND REX BOOTH, *University of California, Livermore.*—Nonelastic (inelastic collision) cross sections were measured for 22 elements by means of the sphere technique. Neutrons at 14.2 Mev for the cross-section measurements were produced by the $H^3(d,n)He^4$ reaction. Calibration of the scintillation detector was accomplished, with the aid of a variable-energy cyclotron, by the $H^2(d,n)He^3$ reaction. Corrections have been applied for elastic energy loss, multiple scattering, finite detector size, obliquity effects, and the nonisotropy and nonisoergicity of the neutron source. Checks have been made on the accuracy of the correction methods, both experimentally and with various analytical and Monte Carlo studies. The corrected cross sections for elements with $Z>10$ are believed to be accurate to 2% or 3%. The uncertainties for the very light elements are somewhat larger. A comparison will be made between the measured nonelastic cross sections and the predictions of the optical model.[1]

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Bjorklund, Fernbach, and Sherman, Phys. Rev. **101**, 1832 (1956).

L9. On $(\alpha,\alpha n)$, $(\alpha,\alpha 2n)$ and $(\alpha,\alpha 3n)$ Excitation Functions.* GEORGE MERKEL, *University of California, Berkeley.*—About 20 excitation functions of the form $(\alpha,\alpha n)$, $(\alpha,\alpha 2n)$, or $(\alpha,\alpha 3n)$ for an incident alpha particle energy up to 48 Mev have been obtained for several nuclides ranging from Ni^{58} to Au^{197}. The $(\alpha,\alpha 2n)$, $(\alpha,\alpha 3n)$, and parts of the $(\alpha,\alpha n)$ excitation functions are consistent with the statistical compound-nucleus theory if the density of states of an excited residual nucleus varies as (const) $\exp(AE_{ex})^{\frac{1}{2}}$, where E_{ex} is the energy of excitation of the residual nucleus and A is a constant of the order of 5 Mev^{-1}. In the case of $(\alpha,\alpha n)$ excitation functions a second reaction mechanism occurs. For the $(\alpha,\alpha n)$ excitation functions obtained so far, the magnitude of this second reaction mechanism is smallest when the equivalent (γ,n) threshold energy is relatively high. If, near threshold, the (γ,n) reaction has a large electric quadrupole component, the second reaction mechanism might be explained as Coulomb excitation. To prove or disprove this Coulomb excitation hypothesis, it probably will be necessary to bombard with particles of higher Z.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

L10. Alpha Particles from the Reaction $T+T=\alpha+2n$.* NELSON JARMIE, ROBERT C. ALLEN, AND W. T. LELAND, *Los Alamos Scientific Laboratory.*—A study is being made of the alpha particles from the reaction $t+t=\alpha+2n$. 1.9-Mev tritons, from an electrostatic generator, bombard gaseous tritium, and the resultant alpha particles are observed at 30° with a 16-inch double-focusing magnetic spectrometer. Preliminary results give an alpha spectrum from 1 to 7 Mev, with peaks appearing at 2 Mev and 5 Mev. These peaks are presumably due to He^5 formation and breakup and are superimposed on the three-body spectrum. Some structure at the end point of the spectrum may possible be due to correlation between the two neutrons. An important improvement in technique is the use of thin glass foils[1] (10 to 20 kev thick to 1-Mev protons) in the tritium gas cell as entrance and exit windows.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] A. Hemmendinger and A. P. Roensch, Rev. Sci. Instr. **26**, 562 (1955).

L11. Angular Distributions of Recoil Nuclei.* J. B. BALL, A. W. FAIRHALL, AND I. HALPERN, *University of Washington.*—The angular distributions of recoil nuclei have been examined in a number of reactions induced by alpha particles of energy up to 43 Mev. A well-collimated beam falls on a thin plated target. The recoils are caught in foils at a distance from the target and are identified radiochemically. Among the results obtained so far are the following: (1) $Ni^{58}(\alpha,\gamma)Zn^{62}$. The cross section for this reaction at 30 Mev has fallen from its peak[1] near 20 Mev by a factor of roughly 10. (2) $Cu^{65}(\alpha,3n)Ga^{66}$ at 43 Mev. Half the recoils are emitted within 11° with respect to the beam. (3) $Co^{59}(\alpha,2n)Cu^{61}$ at 30 Mev. Half the recoils are emitted within 10°. A calculated distribution (based on the "statistical" model) is in qualitative agreement with the observed one. (4) $Cu^{63}(\alpha,n)Ga^{66}$ at 43 Mev. Half the recoils are

emitted within 16°. Under the assumption that less than 8 Mev is carried off by photons, it follows that half the neutrons are emitted within 23°. The recoil technique provides a method for studying "directly ejected" neutrons from high-energy α,n reactions without the interference from other reactions. We are trying to improve the technique to eliminate errors due to the scattering of recoils.

* Supported by the U. S. Atomic Energy Commission.
[1] H. Morinaga, Phys. Rev. **101**, 100 (1956).

L12. Energy Loss and Straggling of 150-Mev Electrons in Li, Be, C, and Al.* A. M. HUDSON,† *Stanford University.*—The most probable energy loss and the straggling distribution for 150-Mev electrons in thin targets (~2.5 g/cm²) of Li, Be, C, and Al have been measured utilizing the electron beam of the Stanford Mark III linear electron accelerator. The primary beam energy spectrum had a full width at half-height of 0.20 Mev. The data for the most probable energy loss agree with the theory of Landau when corrected for the density effect according to Sternheimer. A recent recalculation of this density effect on the basis of new values for the mean excitation potentials after Caldwell[1] noticeably improves agreement between theory and experiment for carbon. Comparison is made with previous calculations using Bakker and Segrè potentials. The half-widths of the straggling distributions are between 7 and 15% wider than the Landau theory predicts, in qualitative agreement with a recent comment by Hines.[2]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Department of Physics, Occidental College, Los Angeles 41, California.
[1] D. O. Caldwell, Phys. Rev. **100**, 291 (1955).
[2] K. C. Hines, Phys. Rev. **97**, 1725 (1955).

FRIDAY AFTERNOON AT 2:30

Spanagel 400

(E. CREUTZ presiding)

Low-Energy Nuclear Physics

M1. Isotope Shift in W^{180}. WILLIAM L. BARR AND F. A. JENKINS, *University of California, Berkeley.*—Using a tungsten sample enriched in the rare isotope 180, the isotope shift between 180 and 182 was measured relative to the 182–184 and 184–186 shifts. A liquid-air cooled hollow-cathode light source and Fabry-Perot etalons with 9-layer dielectric mirrors allowed the rare isotope 180 to be clearly resolved in a few lines. The relative shifts obtained are $\Delta\nu(186\text{–}184)$: $\Delta\nu(184\text{–}182)$: $\Delta\nu(182\text{–}180) = 88:100:68$. This does not agree with the results of either Vreeland and Murakawa,[1] or Murakawa.[2] The latter were obtained using natural tungsten in which the concentration of W^{180} is only 0.13%. Kopfermann and Meyer's[3] conclusions on the shifts for the more abundant isotopes is confirmed. This smaller shift between the lighter tungsten isotopes is somewhat surprising when one considers that the theory[4] would predict nearly equal shifts between all three pairs, increasing slightly toward the lighter isotope.

[1] J. A. Vreeland and K. Murakawa, Phys. Rev. **83**, 229(L) (1951).
[2] Kiyoshi Murakawa, J. Phys. Soc. Japan **11**, 778 (1956).
[3] H. Kopfermann and D. Meyer, Z. Physik **124**, 685 (1947).
[4] Wilets, Hill, and Ford, Phys. Rev. **91**, 1488 (1953).

M2. Spin of 40-Day Ag^{105}.* H. B. SILSBEE, W. A. NIERENBERG, H. A. SHUGART, AND P. O. STROM, *University of California, Berkeley.*—The spin of radioactive (40-day) Ag^{105} has been measured with the result $I = \frac{1}{2}$. The isotope was prepared by the reaction $Rh^{103}(\alpha,2n)Ag^{105}$ in the Crocker 60-in. cyclotron, and its spin was measured by the atomic beam magnetic resonance method. The identification of the isotope responsible for the $I = \frac{1}{2}$ signal was made through its half-life. The result is in agreement with shell model predictions. Further work on radioactive silver isotopes is in progress, and results will be reported.

* Research supported jointly by Office of Naval Research and U. S. Atomic Energy Commission.

M3. Decay of Indium-109 and Tin-109.* MICHAEL D. PETROFF, *University of California, Berkeley.*—On the basis of the investigation of the conversion-electron and γ-ray spectra, a decay scheme for In^{109} is proposed. The decay scheme involves a ground-state spin of 9/2(+) for In^{109} and 5/2(+) for Cd^{109}. The investigation included the measurement of the half-life of a 58-kev $E2$ isomeric transition in Cd^{109} which yielded a value of $12\pm3\times10^{-8}$ sec. The decay scheme requires that the level of Cd^{109} associated with this isomeric transition be the first excited level, with a spin of $\frac{1}{2}(+)$. The 18-min Sn^{109} activity involves at least five γ transitions with the energies 0.335, 0.521, 0.658, 0.887, and 1.12 Mev. The 0.658-Mev transition is an $M4$ transition, suggesting that In^{109} has an isomeric state of the same type as that which occurs in In^{113} and In^{115}.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

M4. Thermal-Neutron Capture Gamma-Ray Spectrum from U^{235}.* ROBERT W. KENNEY AND JAMES T. MATTINGLY, *University of California, Livermore.*—The prompt gamma-ray spectrum initiated by thermal-neutron capture in U^{235} was measured by observing the photon spectrum from a target of U^{235} placed in the WBNS thermal-neutron beam. The photon detector was a three-crystal scintillation spectrometer of conventional design. Three gamma-ray lines were identified. Their energies and their production cross sections were found to be:

E in Mev	$\sigma_{(n,\gamma)}$ barns
4.0±0.1	1.3±0.3
5.9±0.1	0.2±0.07
7.5±0.2	0.1±0.03

The spectral shape corresponds to class 2-*b* of Mittleman, and is typical of heavy elements.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

M5. Decay of Er^{171}.* F. P. CRANSTON, M. E. BUNKER, J. P. MIZE,† AND J. W. STARNER, *Los Alamos Scientific Laboratory.*—The radiations of Er^{171} ($T_{\frac{1}{2}} = 7.80\pm0.18$ hr) have been investigated with β and γ scintillation spectrometers, a magnetic lens, and a 141-gauss, 180° permanent magnet spectrograph. We observe β groups with end-point energies of 1.05 Mev (97%) and 1.49 Mev (~3%), and γ rays with energies (in kev) and multipolarities of 111.5 ($M1$), 116.5 ($E2$), 123.8 ($E2$), 210, 285, 295.4 ($E1$), and 307.5 ($E1$). The above data, to-

gether with the results of β–γ and γ–γ coincidence studies, suggest the existence of the following nuclear levels in Tm^{171}: 5.0, 116.5, 128.8, and 424.1 kev. The 210- and 285-kev γ rays have been observed only in coincidence spectra, and their positions in the decay scheme have not yet been determined. The three lowest of the above levels are thought to be members of a rotational band belonging to the $\frac{1}{2}+(K=\frac{1}{2})$ ground state. The well-known 2.5×10^{-6} sec metastable level at 424 kev is interpreted as the $h_{11/2}$ $(K=7/2)$ particle excitation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Combustion Engineering Inc., Windsor, Connecticut.

M6. Decay of Er^{169}.* E. N. Hatch and F. Boehm, *California Institute of Technology.*—An 8.42-kev rotational level in Tm^{169} with spin $\frac{3}{2}+$ has been reported from studies of the gamma-ray spectrum following electron capture from Yb^{169}.[1] It could be expected that this level would also be excited by beta decay of Er^{169}. A study of the 9.4-day Er^{169} decay using a semicircular spectrometer with transmission down to 2 kev revealed M, N, and O conversion peaks due to the 8.42-kev gamma ray. The observed M sub-shell conversion ratios, $M_I:M_{II}:M_{III}:M_{IV,V}=3:1:1:\leq0.05$, probably indicate $M1+E2$ multipolarity. The end point of the Er^{169} beta spectrum was found at 330 ± 10 kev, and the branching ratio of the decay was determined to be 15% to the 8.42-kev level and 85% to the $K=\frac{1}{2}$ ground state of Tm^{169}. It appears likely that the Er^{169} ground state has spin $\frac{1}{2}-$, corresponding to orbit 63 from the curves given by Mottelson and Nilsson.[2]

* Work supported by the U. S. Atomic Energy Commission.
[1] Hatch, Boehm, Marmier, and DuMond, Phys. Rev. **104**, 745 (1956).
[2] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).

M7. Rotational Levels in Gd^{156}.* F. Boehm and E. N. Hatch, *California Institute of Technology.*—Nuclear energy levels in Gd^{156} populated following beta decay from Eu^{156} have been studied with the curved-crystal gamma-ray spectrometer and the ring-focusing beta-ray spectrometer. The Eu^{156} was formed by triple neutron capture of Eu^{153} during irradiation in the Materials Testing Reactor at Arco, Idaho. Two gamma rays with energies of 88.97 ± 0.01 and 199.19 ± 0.06 kev were found in the low energy region. Both gamma rays have $E2$ multipolarity and represent transitions in the ground-state rotational band. These transitions probably correspond to those observed with neutron capture[1] and Coulomb excitation[2] experiments with Gd. From the energies of the 2+ and 4+ rotational levels (88.97 and 288.16 kev, respectively), the Bohr-Mottelson rotational splitting constant, $\hbar^2/2g$, is computed to be 15.008 kev, and the coefficient of the $I^2(I+1)^2$ correction term is -0.03000 kev. The 88.97-kev level appears to be populated by a 2.45 ± 0.05-Mev electron spectrum and by high energy gamma rays. Evidence for high energy levels up to 2.19 Mev, which are excited by low energy beta groups, is present.

* Work supported by the U. S. Atomic Energy Commission.
[1] E. L. Church and M. Goldhaber, Phys. Rev. **95**, 626 (1954).
[2] Huus, Bjerregaard, and Elbek, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **30**, No. 17 (1956).

M8. Heavy Elements in Supernova. R. P. Schuman, *Knolls Atomic Power Laboratory.**—It has been proposed that the energy from the spontaneous fission of Cf^{254} is responsible for the 55-day decay of the light from Supernova of type 1.[1] The neutron capture process for the production of Cf^{254} should also produce other heavy elements. In order to determine the effect of these nuclides, the decay of energy from all the heavy nuclei was calculated. The composite curve follows the observed decay of B-Cassiopeiae quite well but tails out somewhat more after one year due to energy from Cf^{252} and Ra^{228}. At present, B-Cassiopeiae should still be producing energy due to Cm^{250} and Ra^{226} at a rate corresponding to a stellar magnitude of 16, a value greater than the limit observed by Baade. The decay of light from supernova can be reasonably well explained assuming production of all the heavy elements. However, if the heavy nuclei are produced, the resulting stellar material, after decay, should have a large superabundance of U, Th, Bi, and Pb.[2]

* The Knolls Atomic Power Laboratory is operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] Burbidge, Hoyle, Burbidge, Christy, and Fowler, Phys. Rev. **103**, 1145 (1956).
[2] The author wishes to acknowledge the help of Dr. R. A. Alpher.

M9. Branching Ratios in B^{12} Decay.* C. W. Cook, *California Institute of Technology.*—The β decay of B^{12} has been shown to yield low-energy α particles which arise from the breakup of the 7.7-Mev state in C^{12}. Absolute measurements of the alpha and beta yields by means of a strong focusing magnetic spectrometer and a 5-in. diameter by 4-in. long plastic scintillator respectively, indicate that these α particles are emitted in $1.0\pm0.5\%$ of all the β disintegrations. Experimental evidence suggests that the 7.7-Mev state does not radiate directly to the ground state, but rather cascades via the 4.4-Mev state, thus competing with the α emission. Estimates of the relative probability of the α to γ emission vary but the most recent suggest[1,2] a ratio $>97\%$. The probability for the state to emit nuclear pairs is also expected to be small although 7-Mev pairs have been reportedly observed.[3] It appears therefore that the 7.7-Mev state decays mainly by α emission and hence the β-decay branching ratio can be given very nearly as $1.0\pm0.5\%$.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bent, Bonner, McCrary, and Ranken, Phys. Rev. **100**, 771 (1955).
[2] W. F. Hornyak, Bull. Am. Phys. Soc. Ser. II, **1**, 197 (1956).
[3] G. Harries and W. T. Davies, Proc. Phys. Soc. (London) **A65**, 564 (1954).

M10. Lifetime of the 3^-(6.14 Mev) State of O^{16}.* D. Kohler and H. Hilton, *California Institute of Technology.*—An upper limit has been placed on the lifetime of the 3^- state of O^{16} by the recoil method[1] of 10^{-11} second,[2,3] and a lower limit of 5×10^{-12} second by the Doppler shift method.[3] In the present investigation, the lifetime has been remeasured by the recoil technique with improved resolution. A thin evaporated target of CaF_2 on a highly polished brass block was used as a source of recoil O^{16*} nuclei, from the reaction $F^{19}(p,\alpha\gamma)O^{16}$. For comparison purposes a layer of copper, sufficiently thick to stop the recoils, was evaporated over the CaF_2. The block was moved relative to a tungsten collimator in steps of 50 microinches by a differential thread. Effects due to angular distribution of the recoils, slowing down of the recoils in the CaF_2 and carbon contaminant layers, and γ-ray penetration of the collimator were carefully considered. A value for the half-life of $O^{16}(3^-)$ of $6.4\pm2.8\times10^{-12}$ second was obtained, in agreement with the previously established limits.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. Thirion and V. Telegdi, Phys. Rev. **92**, 1253 (1953).
[2] C. A. Barnes (private communication).
[3] Devons, Manning, and Bunbury, Proc. Phys. Soc. (London) **68**, 18 (1955).

M11. Spin and Magnetic Moment of Eu^{154}.* R. W. Kedzie, M. Abraham, and C. D. Jeffries, *University of California, Berkeley.*—The microwave paramagnetic resonance hyperfine structure of Eu^{154} (15 yr) has been observed in a sample of Eu^{2+} ions incorporated in a powdered sample of KCl. Two samples of Eu^{154} were used, the first prepared by pile neutron bombardment of Eu^{153}, the second by fission of Pu. Each sample gave a paramagnetic resonance spectrum consisting of 6 hfs lines due to Eu^{153} $(I=5/2)$ and 7 weaker lines with the same g value due to Eu^{154}, showing that $I(Eu^{154})=3$. From the ratios of the total hfs splittings for the two isotopes, the magnetic moment ratio was obtained: $|\mu(Eu^{154})|/|\mu(Eu^{153})|$

$=1.308\pm0.004$. Using $\mu(Eu^{153})\cong1.5$ nm [1] we find $|\mu(Eu^{154})|\cong2.0$ nm. To second order, both sets of hfs lines may be fitted to the spin Hamiltonian $H=g\beta(\mathbf{H}\cdot\mathbf{S}+A\mathbf{I}\cdot\mathbf{S})$, where $g=2.00$ and $S=7/2$ for both isotopes and $A(Eu^{153})=16.6$ gauss, $A(Eu^{154})=18.1$ gauss, $I(Eu^{153})=5/2$, $I(Eu^{154})=3$. T. Parsons kindly provided the Eu fission products.

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. Schuler and T. Schmidt, Z. Physik **94**, 457 (1935); **98**, 430 (1955); P. Brix, *ibid.* **132**, 579 (1952).

M12. Gamma-Ray Spectrum of Y^{88}.* F. M. TOMNOVEC, *U. S. Naval Radiological Defense Laboratory.*—A source of Y^{88} was prepared at the University of California Crocker Laboratory 60-in. cyclotron, by bombardment of strontium with 12-Mev protons. The relative intensities and energies of the gamma-ray spectrum were obtained with a 4 in.×4 in. NaI(Tl) crystal and collimator (½-in. diameter cylindrical hole 8 in. long). Using the 1.6-Mev gamma of La^{140} and the 2.76-Mev gamma of Na^{24} a comparison was made that established the energy of the gamma rays between the first excited level and the ground state of Sr^{88} as 1.85 Mev and the cross-over gamma ray as 2.76 Mev. The relative intensities of the 1.85-Mev gamma to the 0.908-Mev gamma is 1.09 and the 2.76-Mev cross-over gamma ray is 0.005% of the 1.85-Mev gamma ray. This is in good agreement with Lazar *et al.*[1]

* This is part of the supplementary program and will be read if the chairman rules that time is available.
[1] Lazar, Eichler, and O'Kelley, Phys. Rev. **101**, 727 (1956).

FRIDAY EVENING AT 8:00

Bali Room

(E. P. WIGNER, presiding)

Banquet of the American Physical Society

After-dinner speech: P. KUSCH

SATURDAY MORNING AT 10:15

King Hall

(R. F. BACHER presiding)

Invited Papers

N1. Astronomical Data on Stellar Evolution. JESSE L. GREENSTEIN, *Mount Wilson and Palomar Observatories, California Institute of Technology.* (30 min.)

N2. Experimental Study of the Feasibility of C^{12} Synthesis from Helium. THOMAS LAURITSEN, *California Institute of Technology.* (30 min.)

N3. Synthesis of the Heavy Elements. WILLIAM A. FOWLER, *California Institute of Technology.* (30 min.)

N4. The Frontiers of Cosmology. FRED HOYLE, *Fellow of St. John's College, Cambridge, and Visiting Professor of Astronomy at California Institute of Technology.* (30 min.)

SATURDAY MORNING AT 9:00

Spanagel 421

(R. B. BRODE presiding)

Mesons II

O1. Mean Life of τ and K Mesons. I. Apparatus.* G. J. MORRIS, R. K. STITT, J. W. KEUFFEL, R. L. CALL, AND W. H. SANDMANN, *University of Utah.*—A single 65-kg liquid scintillation detector is mounted beneath a large generating layer. Those events are selected whose time pattern in the scintillator includes a pulse in the range 0.3–6.6 μsec, indicating that either a μ–e or π–μ–e decay has occurred. Thus K and τ events where a secondary stops within the tank are detected with high efficiency. A total energy release in the detector greater than 150 Mev is required, so that ordinary atmospheric μ mesons are not detected. A novel pulse-forming circuit produces two uniform 5-μsec pulses, one referred in time to the leading edge of the scintillator pulse (the stopping τ or associated time-zero shower particles) and one referred to that time at which the pulse has risen to within about 40 Mev of the *top* (the delayed secondary). The circuit is of general applicability where delayed coincidences *within the same scintillator* are required. The over-all timing precision is about 2 μsec, and

the minimum readable delay about 10 mμsec, the basic limitation being photon time of flight in the very large scintillator.

* Supported by the National Science Foundation.

O2. Mean Life of τ and K Mesons. II. Results.* J. W. KEUFFEL, R. L. CALL, W. H. SANDMANN, G. J. MORRIS, AND R. K. STITT, *University of Utah.*—An experiment is in progress to measure the mean lives of cosmic-ray τ and K mesons using the apparatus described in the previous abstract operating at an altitude of 4670 ft. In the first 30 days, we have obtained 10 τ's and 86 K's, yielding meanlives of 13^{+8}_{-4} mμsec and 11.5 $\pm$2.5 mμsec, respectively. The K-meson result is of interest since it agrees with mean lives obtained at the machines, while other cosmic-ray measurements have tended to give somewhat shorter lifetimes. The present experiment is noteworthy in two respects: we can use the 2.2 μsec decay electrons as an identification, which would be difficult in the high backgrounds near the machines, and we can follow the decay curves closer to the point of production than is possible when using a momentum analyzer. Counting close to production is an advantage in searching for a "break" in the K-particle decay curve, which would result if the $K_{\mu 2}$ mode were really a mixture of leptonic decays from two different particles. So far, our decay curve shows no signs of a "break."

* Supported by the National Science Foundation.

O3. Angular Distribution of Photomeson Yield as a Function of Atomic Number.* E. KNAPP, W. IMHOF,† AND V. PEREZ-MENDEZ, *University of California, Berkeley.*—Angular distributions of the π^+-meson yield produced by the 335-Mev bremsstrahlung beam at the Berkeley synchrotron have been measured for meson energies of 46 and 65 Mev and laboratory angles varying from 46° to 150°. The π–μ detection apparatus used to measure these yields has been improved from that used previously[1] by the addition of a Čerenkov anticoincidence counter which materially reduced the accidental counting rates at the forward angles. The angular distributions of the meson yields follow approximately the angular distributions of the yields from hydrogen produced by the bremsstrahlung beam at these energies. The results, when analyzed by the model of Brueckner, Serber, and Watson,[2] yield mean free paths in agreement with those obtained previously at 135°. Measurements of $F(Z)$ for meson energies of 95 and 125 Mev were also made at laboratory angles of 135° and 90°. Differences in these curves from those obtained at the lower energies are attributed to internal momentum effects.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Lockheed Aircraft Corporation.
[1] William L. Imhof, "Z Dependence of Positive-Pion Production by 335-Mev Bremsstrahlung and 340-Mev Protons," thesis, UCRL-3383, April, 1956.
[2] Brueckner, Serber, and Watson, Phys. Rev. **84**, 258 (1951).

O4. Meson Production in n–p Collisions at Bevatron Energies.* FRED N. HOLMQUIST, WILLIAM B. FOWLER, AND WILSON M. POWELL, *University of California, Berkeley.*—Work was recently begun on the analysis of 473 three-prong events observed in collisions between Bevatron-produced neutrons and protons in a hydrogen-filled diffusion cloud chamber. These events, together with 48 five-prong events and one seven-prong event, have been reported previously.[1] Of the first 30 three-prong events accepted by the IBM 650 computer as consistent within the specified errors of measurement, 23 are probably of type $n+p \rightarrow p+n+\pi^++\pi^-$ and five are probably of type $n+p \rightarrow p+p+\pi^-+\pi^0$. The identification of $n+p \rightarrow p+p+\pi^-$ events is at present uncertain. These first measurements yield an incoming neutron energy spectrum consistent with a flat distribution between one and six Bev. Angular distributions in the center-of-mass system, momentum distributions, and Q values for the three and five prong events will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Fowler, Maenchen, Powell, Saphir, and Wright, Phys. Rev. **101**, 911 (1956).

O5. Ionization Loss by Mu Mesons in Helium.* R. E. LANOU†‡ AND H. L. KRAYBILL, *Yale University.*—The ionization loss by cosmic-ray μ mesons in helium gas has been measured as a function of momentum. The ionization loss was determined with proportional counters and the momenta were measured by a magnetic spectrometer which resolved particles in the momentum region from 3.3 Bev/c to 140 Bev/c. It was found that helium gas at 2.7 atmos pressure exhibits a density-effect saturation of the most probable ionization loss and that this saturation is complete at a $p/\mu c$ value of about 200. Under the conditions of normalization to theory used in this experiment, the value of the ionization loss at which the Fermi plateau occurs is 1.28$\pm$0.04 times the value at the minimum. This is in agreement with calculations, made on the basis of Sternheimer's theory,[1,2] for the particular counter filling used in this experiment.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at the University of California Radiation Laboratory, Berkeley, California.
‡ General Electric Predoctoral Fellow.
[1] R. M. Sternheimer, Phys. Rev. **88**, 851 (1952).
[2] R. M. Sternheimer, Phys. Rev. **91**, 256 (1953) and Erratum, *ibid.* **93**, 1434 (1954).

O6. Z-Dependence of Photopion Production.* W. S. C. WILLIAMS,† K. M. CROWE,‡ AND R. M. FRIEDMAN,§ *Stanford University.*—Accurate measurements of photopion production with 550-Mev bremsstrahlung for several elements will be presented. The analysis in terms of the optical model yields a large variation in effective mean free path λ for different pion energies. The result covers the range $\lambda_{20\ Mev} \sim 10^{-12}$ cm to $\lambda_{120\ Mev} \sim 10^{-13}$ cm. Ways of analyzing this data and data obtained previously are compared. The deviations from the optical model will be discussed.

* The research reported here was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Department of Natural Philosophy, The University, Glasgow, Scotland.
‡ Now at the University of California Radiation Laboratory.
§ Now at Missile Systems Division, Lockheed Aircraft Corporation, Palo Alto, California.

O7. Interaction of Positive K Mesons at Energies of 100 to 200 Mev.* JOSEPH E. LANNUTTI, WARREN W. CHUPP, GERSON GOLDHABER, AND SULAMITH GOLDHABER, *University of California, Berkeley.*—In continuing our study of K-meson interactions with complex nuclei,[1] we recently exposed a stack of nuclear emulsions to a separated positive K-meson beam[2] of momentum 430 to 500 Mev/c. To date we have followed about 15 meters of positive K-meson track in the energy region 200 to 100 Mev. In this path length, 30 inelastic scattering events were found. Within the present limited statistics the mean free path in nuclear emulsions ($\sim$50 cm) is shorter than the value found at lower energies ($\sim$95 cm).[1] In this work all elastic scatters above 2° were recorded and will be compared with similar data for negative O mesons.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Lannutti, Chupp, Goldhaber, Goldhaber, Helmy, Iloff, Pevsner, and Ritson, Phys. Rev. **101**, 1617 (1956).
[2] Exposure in conjunction with Dr. Donald H. Stork.

O8. Example of a Positive $K_{\mu 2}$ Meson from an Antiproton Annihilation Star.* GERSON GOLDHABER AND LOUIS R. JAUNEAU,† *University of California, Berkeley.*—In the study of antiproton annihilation stars in photographic emulsions[1] evidence has been presented from multiple scattering and grain-counting measurements for the emission of K mesons in

about 10% of the stars. We have now found an annihilation star at rest, Number 3-25, emitting one black prong (A) and one gray prong (B). Particle B comes to rest in the stack after a range of 3.87 cm and then emits a near-minimum secondary (B'). The secondary, B', emitted at a 43° dip angle, traverses 147 plates (11.2 cm) and then leaves the stack. Gap coefficient measurements on the track B gives $g/g_{min}=2.38\pm0.23$ and combined with the residual range this yields a mass of 740 ±130 m_e where the statistical error is quoted. Grain counts on the secondary (B') give $g/g_{min}=1.06\pm0.04$ near the decay point and $g/g_{min}=1.11\pm0.04$ after traversing 8 cm. Surface-angle measurements[1] on the secondary track (B') near the decay point give $p\beta=270\pm100$ Mev/c. We conclude from these observations that particle B produced in the antiproton annihilation is most probably a positive $K_{\mu 3}$ meson.

* Supported in part by the U. S. Atomic Energy Commission.
† National Council Fellow under I.C.A. grant.
[1] The Antiproton-Nucleon Annihilation Process, Barkas, Birge, Chupp, Ekspong, Goldhaber, Goldhaber, Heckman, Perkins, Sandweiss, Segrè, Smith, Stork, Van Rossum, Amaldi, Baroni, Castagnoli, Franzinetti, and Manfredini, UCRL-3520, September, 1956; also Phys. Rev. (to be published).

Saturday Morning at 9:00

Spanagel 400

(G. L. Weissler presiding)

Electron Physics I

P1. Orbital Calculation on the Lithium Atom.* George Brigman and F. A. Matsen, *The University of Texas.*—The James and Coolidge calculation on the lithium atom yielded results of high accuracy, but the method is not readily extended to molecules. In an attempt to find a good basis for molecular wave functions, several calculations based on Slater orbitals have been carried out. All functions were antisymmetrized and made eigenfunctions of S^2. The energies are given in units of $R_\infty hc$ and the numbers in parenthesis are effective nuclear charges. $1s^22s$(2.6865, 1.274)$-$14.8358; $1s^22s$(2.6865, 1.274), $1s2s^2$(4.5670, 1.1530), $1s2p^2$(3.4924, 1.5288), $2s2p^2$(5.6056, 1.6562)$-$14.8436; $1s1s'1s''$(3.2825, 2.057, 0.348)$-$14.8549; $1s1s'2s$(3.300, 2.065, 1.283)$-$14.8873. The result for the open configuration, $1s1s'2s$ is lower than that obtained by the Hartree-Fock procedure.

* Supported by the Robert A. Welch Foundation of Houston, Texas, and the Office of Ordnance Research, U. S. Army.

P2. Moving Striations in Argon.* B. W. Hooks, S. H. Kalmbach, and N. L. Oleson, *U. S. Naval Postgraduate School.*—Striations in argon were studied by an arrangement permitting simultaneous observation of any two quantities, such as light intensity and probe current on a dual beam oscilloscope. In a tube of 10.1 mm i.d. with zirconium electrodes and filled with argon at 12 mm pressure, two modes of current and voltage oscillations were observed in the current range of 10 to 105 milliamperes. A smooth variation of frequency *versus* current was found within each mode but an abrupt change occurred between the modes where standing striations were observed. Langmuir plots indicated a 100% variation of electron temperature over the striation cycle, whereas the electron density changed by only 25%. The variation of field intensity over the cycle was in agreement with the results of Pupp. Spectroscopic observations of the light intensity showed that, though the over-all light intensity did not drop to zero, the intensities of the individual spectral lines did. The maxima of the $4P$ to $4S$ occurred 15 microseconds earlier than those of the $5P$ to $4S$ transitions. Negative striations were found close to the cathode and corresponded to an attenuation of the positive striations.

* Supported by the Office of Naval Research.

P3. 3700 A Band of Formaldehyde.* C. M. Loyd and S. E. Hodges, *A. and M. College of Texas* (introduced by J. B. Coon).—The ground-state vibrational level from which the (3700 A) α band of formaldehyde arises has received much discussion in the literature: Recent temperature sensitivity measurements by Cohen and Reid[1] give 1240 ± 50 cm^{-1} for the ground state level of this band. This leads them to the conclusion that the band arises from one quantum of the in-lane bending mode, 1247.4 cm^{-1}.[2] Robinson,[3] on the other hand, interprets the band as arising from one quantum of the out-of-plane bending mode, 1163.5 cm^{-1}.[2] The present temperature sensitivity data support Robinson's interpretation, yielding 1160 ± 23 cm^{-1} for the ground state level from a plot of ln ϵ *vs* $1/T$ that has a slope of 1.67. Measurements were made at eight points in the band on spectrograms taken at temperatures of 403, 439, 472, and 493°K and a path length of 6 meters. Formaldehyde pressures of 5 to 10 cm were used with 120 psi of nitrogen added to insure pressure broadening.

* Supported by the Air Force Office of Scientific Research of the ARDC.
[1] A. D. Cohen and C. Reid, J. Chem. Phys. **24**, 85 (1956).
[2] H. H. Blau, "Infrared measurements," Ph.D. thesis, Ohio State University, Columbus, Ohio, 1955.
[3] G. W. Robinson, Can. J. Phys. **34**, 699 (1956).

P4. Considerations Regarding the Sodium Lines in Twilight and Nightglow. A. Omholt, *University of Chicago** (introduced by J. W. Chamberlain).—Oxidation of sodium by molecular oxygen and subsequent reduction by both atomic oxygen and atomic hydrogen has been examined. It is found that these processes may explain the height of the sodium emission in twilight and nightglow, provided the rate coefficients (which are not well known) are suitable. Several processes may contribute to the diurnal variations in the intensity, and even qualitative predictions are difficult. It has been suggested by D. M. Hunten that photoionization of sodium may explain the seasonal intensity variations, and this process has been examined in some detail. It would probably be most important to the twilight intensity. An important difficulty is that the required number of sodium ions would be approximately equal to the total ionization in the D-layer. However, Bates and Seaton have shown this to be unlikely, because it would require the D-layer to show only small diurnal variations.

* Fulbright Research Fellow, on leave from The Auroral Observatory, Tromsö, Norway. This research was supported in part by Air Force Cambridge Research Center.

P5. Short Time-Resolution Spectrophotometric Study of Pulsed Microwave Discharges in Helium.* R. C. Sill† and J. H. Miller, *Stanford Research Institute.*—Light curves (light intensity as a function of time) of eleven helium emission lines excited at ~12 mm Hg pressure by 2 microsecond pulses of 3 cm microwaves were studied with apparatus having a 50 millimicrosecond response time. The lines ranged from

$\lambda 3614 (5^1P \rightarrow 2^1S)$ to $\lambda 10{,}829 (2^3P \rightarrow 2^3S)$. The discharges occurred in a section of large x-band wave guide having a mica window in each end. The emitted light fell rapidly to zero at the end of the power pulse. Pronounced afterglows (~20 microsecond duration) occurred for triplet transitions with decreasing azimuthal quantum number (l). Singlet transitions and triplet transitions with increasing (l) had no measurable afterglow until the mass spectroscopically checked helium was further purified by cataphoresis whereupon afterglows developed similar to the decreasing (l) triplet afterglows which themselves strengthened with increasing gas purity.[1] No satisfactory explanation has been found for these afterglow variations.

* Supported by the Engineer Research and Development Laboratories, Fort Belvoir, Virginia.
† Now at New Mexico Institute of Mining and Technology, Socorro, New Mexico.
[1] See Janin and Eyraud, Compt. rend. **237**, 1073 (1953) (done with apparatus having poorer time resolution).

P6. Ionization Potentials and Electron Affinities of Some Aromatic Hydrocarbons.* RICHARD M. HEDGES AND F. A. MATSEN, *The University of Texas.*—Pople has suggested that a good approximation to SCFMO energies of aromatic molecules can be obtained by using the Huckel MO coefficients in place of the self-consistent coefficients. This formulation permits a straightforward calculation of the ionization energies and electron affinities.[1,2] This calculation has been programmed for the IBM 650 for 25 aromatic hydrocarbons using Pariser's semiempirical Coulomb integrals.[3] The agreement for the five compounds calculated by Pople and the 25 estimated by Matsen is fair. The F matrix obtained in the course of the calculation can be used to obtain an improved set of coefficients.

* Supported by the Robert A. Welch Foundation of Houston, Texas.
[1] N. S. Hush and J. A. Pople, Trans. Faraday Soc. **51**, 600 (1955).
[2] F. A. Matsen, J. Chem. Phys. **24**, 602 (1956).
[3] R. Pariser, J. Chem. Phys. **24**, 257 (1956).

SATURDAY AFTERNOON AT 2:00

King Hall

(W. K. H. PANOFSKY presiding)

Invited Papers

Q1. Performance of the Cal. Tech. Synchrotron up to 1.2 Bev. MATTHEW SANDS, *California Institute of Technology.* (30 min.)

Q2. Calculations on the Design of Charged-Particle Spectrometers. JOHN F. STREIB, *University of Washington and Stanford University.* (30 min.)

Q3. Detection of Antineutrons and Total Cross Section of Antiprotons in Hydrogen. BRUCE CORK, *University of California, Berkeley.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Spanagel 421

(W. SHOCKLEY presiding)

Electron Physics II

R1. Magnetodynamic Plasma Phenomena. WALTER J. GRAHAM, *Naval Research Laboratory.*—The behavior of high density plasmas is currently receiving much attention. Of particular concern are magnetohydrodynamic instabilities. In this connection a report will be given here of several phenomena which have been observed in high density steady-state plasmas excited by induction fields. A particularly stable mode can be obtained under certain conditions in which a spherically uniform brilliant fireball (~10 cm diameter) appears, with no applied magnetic field. When a field of a few hundred gauss is applied, a spark streak forms essentially in the $\mathbf{j} \times \mathbf{B}$ direction, and will remain stably imbedded in the plasma for at least several minutes. Under higher density conditions, sprays of such spark streaks are produced spontaneously under turbulent conditions from the self-magnetic field of plasma currents. At very high powers the spark streaks show lateral instabilities (breaking up into small pieces); however, under certain conditions, stability against lateral perturbation has been observed in the form of rippled spark streaks. Representative photographs will be shown.

R2. Irreversible Trajectories to Prevent Breakdown in Electron Tubes.* C. HARTMAN AND D. H. SLOAN, *University of California, Berkeley* (introduced by J. R. Woodyard).—A field emission tube with shielded emitters had an electric field shaped to protect it from bombardment by ions from the anode. 100 kv dc operation was steady with the anode molten and bathed in anode vapor plasma. A similar protection by magnetic fields is being used to develop a high voltage beam for traveling wave tubes.

* This work was supported by the U. S. Air Force.

R3. High Current Hydrogen Switch Tube.* W. K. SEIFERT AND D. H. SLOAN, *University of California, Berkeley* (introduced by J. R. Woodyard).—This depends upon a remarkable insulator which has its surface vaporized during each pulse to remove conductive contamination. Immediate reapplication of 20 kv dc is held along a surface of 3 mm length. The inductance of the tube is about two millimicrohenries, and currents of 100 000 amperes are switched on.

* This work was supported by the Air. Force.

R4. Mass Analysis of Positive and Negative Ions From Current Loading In a One Megavolt Accelerating Tube.* J. L. MCKIBBEN AND JAMES HENSHALL, *Los Alamos Scientific*

Laboratory.—An accelerating tube, as used in an electrostatic generator, will under certain conditions give a continuous discharge of ions and electrons[1] which originate at metallic surfaces. The phenomenon, also known as current loading, has a sharp onset threshold which depends upon the shape and bias of the ends, material, conditioning, residual vacuum pressure, etc. The experiment was done with the high voltage end plate being a flat electrode of 2024 aluminum alloy and with the grounded end of the tube being a conical electrode of aluminum alloy, 10° from flat, with a 1-in. hole in the center. The tube section was 20 in. long with 40 flat aluminum alloy electrodes 6½ in. i.d. and had a threshold of approximately one megavolt with the above ends. The diffusion pumps used mercury and the trap was liquid nitrogen cooled. The ions escaping from the hole were focused into a line by a single quadrupole lens and deflected with an electromagnet just beyond the lens. The ions were observed both by their fluoresence on a ZnS covered glass plate and by a beam cup assembly and electrometer. The positive ions observed were largely Al^+ with H^+ being about ⅓ as intense. Preliminary data on the negative ions, obtained by reversing the polarity of the generator, showed presence of H^-, O^-, and apparently Cl^-, AlO^-, and AlO_2^-.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] McKibben and Boyer, Phys. Rev. **82**, 315(A) (1951).

R5. Production of Secondary Ions from Metallic Surfaces Bombarded by High-Energy Positive Ion.* W. T. LELAND AND R. A. OLSON, *Los Alamos Scientific Laboratory.*—Measurements have been made as to the quantity and kind of secondary ions produced at metallic surfaces bombarded by positive ions with energies in the range 25–150 kev. Well-defined beams of H^+, N^+, N_2^+, and Kr^+ primary ions were produced with a small Cockcroft Walton set in conjunction with magnetic analyzer and a series of apertures. The primary beam in each case struck the target surface at an angle of 60° to the normal. An electric field normal to the target surface accelerated the secondary ions and in conjunction with suitable apertures and electrodes formed a beam of secondary ions which was subsequently subjected to magnetic analysis and measurement of intensity. Results indicate that the number of secondary ions produced is relatively independent of the primary ion energy in the range covered. Surface conditions are important and changeable when bombardment is started. After a few hours of operation however, results are obtained which are reproducible to ±25% over a period of days. Preliminary results for the number of negative secondary ions per primary ion from a steel target are given below for 100-kev primary ions of various types.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

R6. Secondary Photoelectric Liberation and Quantum Efficiency, γ_p, of Borosilicate Glass. VIJAY K. ROHATGI, *The University of California, Berkeley* (introduced by L. B. Loeb).—The prominence of electrical breakdown phenomena in glass cells with external electrodes, especially at low frequencies, requires a knowledge of the second Townsend coefficient for glass and whether electrons plastered onto glass are liberated by visible or other light. Light from a Heraeus quartz Hg arc liberates $\sim 10^{-12}$ amp/cm² presumably from superficial alkali impurity atoms of borosilicate glass, the positive alkali ions formed increasing the normal conductivity of the glass tenfold. The quantum efficiency of the process, γ_p, is 10^{-4} for 2537 A in vacuum compared to 10^{-12} for a gold film. There is no electron conduction in this glass and electrons plastered onto it from external sources are bound to surface states of such potential that they cannot be liberated by photons <5 volts. This agrees with negative charging of Pyrex in contact with oxidized Ni of work function ~5.5 volts. Light from an A glow discharge appears to have a quantum efficiency $\sim 10^{-3}$ at 10^{-1} mm pressure compared to 10^{-1} for Pt as observed by G. L. Weissler.

R7. Phenomena Delineating the Transition of a Glow Discharge to a Transient Power Arc in Various Gases. RUSSELL G. WESTBERG, *University of California, Berkeley* (introduced by L. B. Loeb).—The transition of a suddenly overvolted abnormal glow discharge in air, N_2, pure A, and pure H_2 at from 0.09–0.20 mm pressure to a transient power arc in a 150 cm long 4 cm diameter discharge tube with disk electrodes, is analyzed by a fast sweep oscilloscope. Triggering on the bright cathode flash initiating the breakdown, the time of passage of luminous pulses, or pips, at various points in the discharge as well as the potential variations at a number of probes down the tube and the cathode currents as a function of time can be observed. Thus fairly complete data indicate the breakdown to start from the cathode as a steep potential front advancing down the tube producing luminosity and ionizing as it goes, followed by a return pulse traveling from the anode to complete the ionization. Velocities depend on potential gradient, electron density and pressure reaching values up to 3×10^9 cm/sec in H_2. An influence of circuit constants on current is noted.

R8. Thermionic Properties of the (211) Tantalum Crystal. HAYWOOD SHELTON,* *The Ramo-Wooldridge Corporation* (introduced by D. B. Langmuir).—This investigation uses two (211) crystals in tantalum ribbon as emitter and collector in a three-element retarding potential experiment. The electrons from one crystal are accelerated through a small aperture which, in conjunction with a strong axial magnetic field, collimates a beam and directs it to the collector crystal. The uniform-work-function of single crystals, the plane geometry, and the collimating magnetic field remove the deleterious effects of conventional retarding potential experiments that prevent the exact determination of the energy distribution. The resulting retarding potential plot is extremely close to the theoretically predicted two intersecting straight lines on semilog paper, with the transition region extending less than 20 mv. This indicates a perfect Maxwellian distribution with no large energy-dependent reflection. A slowly varying 6% reflection as predicted by the quantum mechanics is observed. The temperature, saturated current density, and the temperature derivative of the work-function as found from different retarding potential plots are used in a Richardson analysis to derive the thermionic constants. For the clean (211) tantalum crystal used the practically temperature-independent work-function is 4.352 ± 0.01 volts and the emission constant A is 120 amp/cm²-°K².

* The work described was performed at Massachusetts Institute of Technology.

R9. Studies of the Oxide Cathode in Demountable Vacuum Systems. GEORGE A. HAAS AND JOHN T. JENSEN, JR., *U. S. Naval Research Laboratory.*—Results of various Ba–Ni matrix and Ba–W matrix cathodes indicate that the conventional oxide cathode would give the best emission characteristics if the problem of flaking of the cathode coating could be controlled.[1] This phenomenon has been investigated and is believed largely a result of repeated lattice expansion and contraction. This occurs as the oxide changes to the hydrate upon air exposure and then is reconverted to the oxide subsequent to heating in vacuum. Thermionic emission studies, chemical analysis, and photomicrographs of the coating surface indicate that a small filament voltage applied to the cathode during air exposure prevents the formation of the hydrate and greatly reduces the problem of cathode flaking.

[1] G. A. Haas and J. T. Jensen, Jr., *Proceedings of the Third National Conference on Tube Techniques* (New York University Press, New York, to be published).

R10. Investigation of [Ag]–Cs_2O, Ag, Cs as a Thermionic Emitter. J. E. DAVEY, *Naval Research Laboratory.*—Quantitative measurement of thermionic work function, photoelectric work function, and electrical conductivity have been made on surfaces activated to near maximum thermionic yield. These data have been used in an attempt to describe the energy level diagram according to a simple one-donor level model. The limitations of the agreement between the data and this model will be discussed.

R11. Theory of the Baro-Galvanic Effect. E. T. BENEDIKT, *Douglas Aircraft Company, Inc.*, S. KYROPOULOS, *California Institute of Technology*, AND J. J. GROSSMAN, *Parsons Engineering Company.*—Any electrolytic cell subjected to gravity, or more generally, inertial forces, exhibits a potential difference across its electrodes, and is capable of producing a current if the latter are connected. Electric fields of the order of 10^{-8} volt/cm due to this effect have been observed. The effect is universal, but more pronounced for certain electrolytes (generally those for which the difference in weight between the cation and the anion is large). The possibility of a "gravity cell" was apparently first noted by Gay-Lussac in 1819; it was since investigated experimentally, and from the point of view of thermodynamic theory by a number of authors. The present contribution deals with a theory of the baro-galvanic effect, based on the impossibility of discharge of cations, and their consequent accumulation around an electrode. The theory covers also the case of variable applied inertial forces, i.e., transient phenomena in a cell subjected to a changing acceleration. Some possible applications of the effect to the determination of the complexity of ions, as well as the interesting (but at present purely theoretical) possibility of an electromechanical accelerometer will be discussed.

R12. Cold-Cathode Electron Source.* J. R. WOODYARD, *University of California, Berkeley.*—This report covers fundamental studies of magnetically-constrained low-pressure gas-conduction devices as electron sources. If a perforated anode is placed between two cathodes in a dc magnetic field oriented parallel to the electric field, a unique type of gaseous conduction occurs. Large currents flow at far lower gas pressures than is the case in the absence of the magnetic field. Heretofore the only applications have been as a vacuum gauge (Penning or Phillips ion gauge) and as an ion source in nuclear accelerators. By perforating one of the cathodes and applying a positive potential to a nearby electrode large currents of electrons have been obtained. Because of the low gas pressure, no interference with the operation of the remainder of the tube as a conventional high-vacuum tube is to be expected. Electron beam current densities approaching 100 amp per square centimeter pulsed and over one ampere per square centimeter dc have been obtained at pressures lower than 10^{-5} mm of mercury. By raising the central anode potential to 3000 volts, conduction has been obtained at the lowest pressures obtainable, less than 10^{-8} mm.

* This work was supported by the U. S. Air Force.

SATURDAY AFTERNOON AT 1:30

Spanagel 400

(A. F. KIP presiding)

Nuclear and Electron Resonance

S1. Magnetic Relaxation in Thin Films. DONALD O. SMITH, *Massachusetts Institute of Technology.*—A static and dynamic theory are proposed to describe the behavior of thin magnetic films having a uniaxial anisotropy energy $E = K \sin^2\theta$. The theory predicts a reversible hysteresis loop transverse to the axis of lowest anisotropy energy with saturation occuring at a field of $2K/M$. The effect of a transverse dc field is investigated; such a field reduces the coercive force of the longitudinal loop and may also lead to asymmetrical loops if the magnetic axis is not kept perpendicular to the dc field. The dynamic theory is based on the Landau-Lifshitz equation and considers the application of impulse fields. An expression for the relaxation time is given which depends on the direction of the impulse field with respect to the anisotropy axis. With an impulse field of $2K/M$ the relaxation time varies from ∞ to 0.1 mμsec as the direction of the impulse field varies from being aligned with the magnetic axis to being perpendicular to this axis. Both reversible and irreversible processes can occur in this time range. The theory is also extended to treat the problem of domain wall motion. Experimental results using a drive pulse with a rise time of 0.2 mμsec and observation of the relaxation behavior by means of a traveling-wave-tube oscilloscope having a band width of 3000 mc will be reported.

S2. Hyperfine Structure in the Electron Spin Resonance of Irradiated Simple Organic Materials. J. B. DRAHMANN, T. H. ANDERSON, AND R. S. ALGER, *U. S. Naval Radiological Defense Laboratory.*—The electron spin resonance induced in solid methanol, ethanol, and acetone by bombardment with 2-Mev electrons was observed in a spectrometer operating at 320 and 640 megacycles. At liquid nitrogen temperature these materials exhibit a hyperfine structure centered about a peak near the free electron g value. The number of observed peaks, the splitting between side bands and the relative intensities of the absorption peaks are as follows: methanol, 3 peaks, 38 gauss splitting, 1:2:1 intensity ratios; ethanol, 5 peaks, 84 and 42 gauss splitting; acetone, 5 peaks, 40 and 21 gauss splitting. The relative intensities of the peaks in acetone varied with exposure, e.g. ratios of about 1:9:1 at low exposures for the 40 gauss splitting became 1:2:1 when the exposure was increased by a factor of 8. When the ratio is 1:2:1 the side bands with 21 gauss splitting are nearly absorbed in the central peak. The structure observed in methanol corresponds qualitatively with the splitting to be expected from electrons interacting equally with 2 protons in the radical ion. CD_3OH was compared to CH_3OH; however, the smaller splitting obtained with the deuterium leads to a broad absorption with unresolved structure. The variable ratio of intensities in the acetone spectra suggest the presence of several species which do not saturate under irradiation at the same rate.

S3. Paramagnetic Resonance of Curium.* M. ABRAHAM, B. B. CUNNINGHAM, C. D. JEFFRIES, R. W. KEDZIE, AND J. C. WALLMANN, *University of California, Berkeley.*—The microwave paramagnetic resonance of 185 μg of Cm^{244} as Cm^{3+} ions incorporated in a 183 mg single crystal of anhydrous $LaCl_3$ has been observed at 77°K using apparatus

previously described.[1] The spectrum consists of 7 lines and, to first order, may be fitted by the spin Hamiltonian $\mathcal{H}=g\beta\mathbf{H}\cdot\mathbf{S}+D[S_z^2-(\frac{1}{3})S(S+1)]$, where $g\cong 2.00$, $S=7/2$, and $D\cong 0.0010$ cm^{-1}. The spectrum is similar but not identical to that of Gd^{3+} in the same crystal structure. These results indicate that Cm^{3+}, like Gd^{3+}, has a ground state $^8S_{7/2}$. Qualitatively similar results have been obtained by Smaller.[2]

* Supported in part by the U. S. Atomic Energy Commission.
[1] Dobrowolski, Jones, and Jeffries, Phys. Rev. **101**, 1001 (1956).
[2] B. Smaller (private communication).

S4. Ground State of Mn^{++} in Crystals.* R. BERSOHN AND T. P. DAS, *Cornell University.*—Mn^{++} is a typical $^1S_0$ state ion whose spin degeneracy is lifted in the solid state. This is explained by the action of spin orbit coupling and spin-spin interaction. To test the latter theory the wave function of Mn^{++} as distorted by the field gradient of a unit charge at distance R was calculated variationally. The expectation value of the spin-spin interaction in the perturbed state becomes a term $D(3S_z^2-S(S+1))$ in the spin Hamiltonian where

$$D=\frac{2}{R^5}g^2\beta^2\{D_{d\to d}+D_{d\to g}+D_{d\to s}\}.$$

Tentative values for $D_{d\to d}$, $D_{d\to g}$, and $D_{d\to s}$ are -0.020, -0.028, and 0.118, respectively. The final result is a factor which converts experimentally measured D's into field gradients. A rough estimate of the field gradient at the site of a Mn^{++} impurity in $CaCo_3$ is threefold larger than the "experimental" field gradient. Considering the approximations, the results support the spin-spin interaction theory.

* Supported by U. S. Atomic Energy Commission.

S5. Nuclear Spin Lattice Relaxation Time in Metals. ALFRED G. REDFIELD, *IBM Watson Laboratory.*—The relaxation time has been calculated for arbitrary dc applied field H_0, using a generalization[1] of the Wangsness-Bloch formalism, and assuming the spins are described by a temperature. When H_0 is small compared to the nuclear dipole fields, all the spin energy is dipolar energy. The dipolar interaction energy of two spins will change if either of the two spins are relaxed. Therefore at very low fields the relaxation time is half its high field value (characteristic of single spin relaxation[2]), if neighboring spins are independently relaxed. These conclusions are altered if account is taken of the finite wavelength of the electrons which are responsible for relaxation. There is a correlation between the fluctuating fields produced by these electrons at near neighbors, and a corresponding correlation between relaxation of near neighbors. In this case the relaxation time also depends on the amount of exchange-type coupling between nuclear spins.

[1] F. Bloch, Phys. Rev. (to be published); A. Redfield, IBM J. (to be published).
[2] J. Korringa, Physica **16**, 601 (1950).

S6. Nuclear and Electron Spin Resonance in Liquid N_2O_4. C. H. HOLM AND W. H. THURSTON, *Shell Development Company,* AND H. M. MCCONNELL AND N. DAVIDSON, *California Institute of Technology.*—We have measured the electron and N^{14} magnetic resonance line widths (ΔH, derivative curve peak-to-peak) for various concentrations of the $N_2O_4 \rightleftharpoons 2NO_2$ equilibrium mixture in liquid CCl_4 solvent at 27°. In going from $\sim$10 molar N_2O_4 (pure liquid) to 10^{-3} molar N_2O_4 the electron ΔH *increases* from 155 gauss (465 Mc) to 227 gauss and the line shape changes from Gaussian to Lorentzian. In pure liquid N_2O_4 the N^{14} resonance shape at 7000 gauss and 2.15 Mc is Gaussian with $\Delta H=50$ gauss; in more dilute solutions the N^{14} resonance is broadened to a point that it is not detectable. These results suggest electron spin exchange to be an important line sharpening mechanism in both the electron and nuclear resonances; in this case only an upper limit can be given for the lifetime of diamagnetic N_2O_4 with respect to dissociation to paramagnetic NO_2: $t_{N_2O_4}<(2\pi)^{\frac{1}{2}}/\gamma\Delta H\sim 2.5\times 10^{-6}$ sec.

S7. Nuclear Magnetic Resonance Spectra of Sodium-Ammonia Solutions. HARDEN M. MCCONNELL, *California Institute of Technology,* AND C. H. HOLM, *Shell Development Company.*—Knight shifts (ΔH) of N^{14} and Na^{23} were observed at room temperature and 7000 gauss as a function of the mole ratio $R=$(moles NH_3)/(moles Na) for $10\lesssim R\lesssim 1000$. $d\Delta H/dR$ is negative; for $R\approx 10$, $\Delta H(N^{14})\approx 4$, $\Delta H(Na^{23})\approx 1$ gauss. $P(N^{14})$ and $P(Na^{23})$ are the average contact densities of N^{14} and Na^{23} nuclei at an unpaired electron and were estimated from $K-NH_3$ paramagnetic susceptibility data and the ΔH's. For $50<R<400$, $P(Na^{23})=5-3\times 10^{-3}$ $P^\circ(Na^{23})$ where $P^\circ(Na)$ is the contact density in an isolated sodium atom; here we conclude the odd electrons more in highly expanded orbitals about Na^+ ions similar to those appropriate to P^+ ions in P-doped silicon where a similar reduction in contact hyperfine density is found.[1] Marked electron condensation on Na^+ ions occurs at $R\lesssim 50$ where $P(Na^{23})$ and electrical conductivity increase rapidly. $P(N^{14})=0.1$ $P^\circ(N^{14})$ independent of R. H^1 Knight shifts are too small to detect.

[1] W. Kohn and J. M. Luttinger, Phys. Rev. **97**, 883 (1955).

S8. Measurement of T_1 and T_2 of Electron Spins in Sodium-Ammonia Liquid Using Pulsed rf. R. J. BLUME, *Columbia University.*—The cw measurements of Hutchison and Pastor[1] of electron spin resonance in alkali metal-ammonia solutions indicated that the spin-lattice relaxation time $T_1\approx 2$ to 5 times T_2. Preliminary measurements at 24 mc on a single sodium-ammonia sample (concentration crudely estimated to be 0.3 mole per liter), using the free precession method of Hahn[2] to measure T_2 and the 180°–90° pulse pair method of Carr and Purcell[3] to measure T_1, indicate that $T_1\approx T_2(=2.9$ μsec), as expected for liquids under the assumption of short correlation times. Spin echoes[2] from electrons have also been produced.

[1] C. A. Hutchison, Jr., and R. C. Pastor, J. Chem. Phys. **21**, 1959 (1953).
[2] E. L. Hahn, Phys. Rev. **80**, 580 (1950).
[3] H. Y. Carr and E. M. Purcell, Phys. Rev. **94**, 630 (1954).

S9. Transient Electron Induction Signals from Sodium-Ammonia Solutions.* V. L. POLLAK AND R. E. NORBERG, *Washington University.*—We report the observation of electron induction decay signals from solutions of sodium in liquid NH_3. The signals appear following the application of fractional microsecond 30 mc radio-frequency pulses to samples in a 10.7 oe static magnetic field. The initial tuning of the oscillator, radio-frequency bridge, and signal amplifier is accomplished by observation of transient piezoelectric signals from an $NH_4H_2PO_4$ powder sample inserted into one of the high impedance coils of the bridge. Measurements of electron relaxation times in the metal-ammonia solutions have been made with both photographic and electronic integrating techniques. The dependence of the transient induction signals upon the spacing of the pulses has yielded an electron T_1 of 2.0 microseconds in a sample of about 0.2 molar concentration. Further measurements corresponding to other concentrations will be reported.

* Supported in part by the Office of Naval Research and the U. S. Air Force Office of Scientific Research of the Air Research and Development Command.

S10. Induced Spin Transitions by Nutation-Precession Interaction.* E. L. HAHN AND D. E. KAPLAN, *University of California, Berkeley.*—In the Bloembergen-Pound-Purcell spin-lattice relaxation theory, transitions between spin states are caused by fluctuating fields at a given spin due to lattice motion of "adjacent" spins. In our double resonance experiment the fluctuations are caused by rf irradiation of the "adjacent" spins in a solid, where the BPP relaxation due to

molecular motion is relatively small. Spins A with resonance at ω_A are coupled to spins B (with gyromagnetic ratio γ_B) which are irradiated with rf field H_1 at frequency $\omega_B \gg \omega_A$. A maximum in the relaxation rate of A is observed at the condition $\gamma_B H_1 = \omega_A$. When the nutational frequency $\gamma_B H_1$ of B is equal to the precessional frequency of A, the $I_{Z,B} I_{\pm A}$ component of magnetic dipole-dipole interaction becomes secular. At the relaxation maximum, direct proportionality between H_1 and ω_A is confirmed in a single crystal of $NaClO_3$ for both chlorine isotopes, where $Na \equiv B$ (quadrupole splitting $\sim$400 kc) and $Cl \equiv A$ (Zeeman splitting $\sim$5 to 20 kc). Predicted maxima in the relaxation at more than one H_1 value for a given ω_A are confirmed in the quadrupole system.

* Supported mainly by the Office of Naval Research and initially by a Research Corporation grant-in-aid.

S11. Paramagnetic and Optical Absorption Spectra of Ni^{2+} in MgO.* W. Low,† *University of Chicago.*—The paramagnetic resonance spectrum of Ni^{2+} in cubic MgO was observed at room, liquid nitrogen, and liquid helium temperatures at 1.25 cm. The spectrum shows one line at $g=2.225 \pm 0.005$ ($T=290$°K), $g=2.227 \pm 0.005$ ($T=70$°K), $g=2.234 \pm 0.002$ ($T=4$°K). The optical absorption spectrum on the same crystal showed intense lines at 8600, 13 700, 14 700, and 24 500 cm^{-1} and weaker lines at 21 750, 25 950, and 28 300 cm^{-1}. All these lines can be accounted for with a crystal field strength parameter $Dq=865$ cm^{-1} and the energy levels of the D, P, G, and S state at 11 000, 12 900, 19 600, and $\sim$55 000 cm^{-1} above the F level. These levels are lower by about 2000 cm^{-1} than those of the free ion. Using these data one computes the spin-orbit coupling parameter in this crystal to be 249 cm^{-1}. The results can be explained that the electrons spend about 4% of their time on each $\psi(\sigma)$ orbit on each oxygen atom.

* Supported by the U. S. Atomic Energy Commission.
† On leave of absence from the Hebrew University, Jerusalem, Israel.

Author Index to Papers Presented at the 1956 Monterey Meeting

Abraham, M., B. B. Cunningham, C. D. Jeffries, R. W. Kedzie, and J. C. Wallmann—S3
Adams, E. N.—A1
Alger, R. S., J. B. Drahmann, and T. H. Anderson—F4
Allen, William A., Earle B. Mayfield, and Harvey L. Morrison—C3
Allison, S. K.—G5
Anderson, John D., Duane C. Gates, Thomas L. Jenkins, Robert W. Kenney, Charles A. McDonald, Jr., and William P. Swanson—B5
Anderson, T. H. and R. S. Alger—F3
Annis, M., N. F. Harmon, and R. D. Sard—B11
Backman, Marvin E.—C4
Ball, J. B., A. W. Fairhall, and I. Halpern—L11
Barber, W. C.—L2
Barr, William L. and F. A. Jenkins—M1
Bell, M. D. and W. J. Leivo—H7
Bemski, G. and W. M. Augustyniak—F6
Benedikt, E. T., S. Kyropoulos, and J. J. Grossman—R11
Bents, U. H.—H8
Bersohn, R. and T. P. Das—S4
Blitzer, Leon—C1
Bloch, Felix—D1
Bloom, M.—J4
Blume, R. J.—S8
Boehm, F. and E. N. Hatch—M7
Bovarnick, Bennett—H3
Brigman, George and F. A. Matsen—P1
Brown, K. L. and W. K. H. Panofsky—B10
Conzett, Homer E. and Robert Silver—L7
Cook, C. Sharp—C7
Cook, C. W.—M9
Cork, Bruce—Q3
Cork, Bruce, William A. Wenzel, and C. W. Causey, Jr.—B6
Cranston, F. P., M. E. Bunker, J. P. Mize, and J. W. Starner—M5
Darrow, K. K.—A4
Davey, J. E.—R10
Drahmann, J. B., T. H. Anderson, and R. S. Alger—S2
Drell, S. D. and F. Zachariasen—I7
Emeleus, K. G.—E2
Feher, G.—J2
Fite, W. L.—E3
Forrester, A. Theodore—A2
Fowler, William A.—N3
Gartenhaus, S. and C. L. Schwartz—I4
George, W. D.—L1
Gibbons, Mathew G.—C9
Glassgold, A. E., W. B. Cheston, S. Schuldt, and G. W. Erickson—I9
Glover, R. E., III—A3
Goldhaber, Gerson and Louis R. Jauneau—O8
Goldhaber, M.—G4
Graham, Walter J.—R1
Greenstein, Jesse L.—N1
Greider, Kenneth R.—B8
Gutmann, Felix—H5
Haas, George A. and John T. Jensen, Jr.—R9
Hagedorn, F. B.—L4
Hahn, E. L. and D. E. Kaplan—S10
Halpern, F. R.—I2
Happ, W. W. and W. Shockley—H11
Harmon, N. F., M. Annis, and R. D. Sard—K11
Hartman, C. and D. H. Sloan—R2
Hatch, E. N. and F. Boehm—M6
Heckman, H. H., F. W. Inman, C. J. Mason, N. A. Nickols, F. M. Smith, W. H. Barkas, W. F. Dudziak, and P. C. Giles—K8
Hedges, Richard M. and F. A. Matsen—P6
Heine, V.—H1
Helmholz, A. C.—G3
Henley, E. M.—I8
Holm, C. H., W. H. Thurston, H. M. McConnell, and N. Davidson—S6
Holmquist, Fred N., William B. Fowler, and Wilson M. Powell—O4
Hooks, B. W., S. H. Kalmbach, and N. L. Oleson—P2
Hoyle, Fred—N4
Hubbs, J. C.—G2
Hudson, A. M.—L12
Hutson, A. R.—H4
Igo, G., R. M. Thaler, and D. L. Hill—I10
Inman, F. W., C. J. Mason, N. A. Nickols, F. M. Smith, W. H. Barkas, W. F. Dudziak, P. C. Giles, and H. H. Heckman—K10
Inn, Edward C. Y. and C. P. Butler—H6
Jarmie, Nelson, Robert C. Allen, and W. T. Leland—L10
Kalbach, R. M., R. Gersten, Y. B. Kim, J. J. Lord, and C. H. Tsao—B4
Kaplan, Selig N., George P. Millburn, Burton J. Moyer, and Robert V. Pyle—B7
Kedzie, R. W., M. Abraham, and C. D. Jeffries—M11
Kenney, Robert W. and James T. Mattingly—M4
Keuffel, J. W., R. L. Call, W. H. Sandmann, G. J. Morris, and R. K. Stitt—O2
Knapp, E., W. Imhof, V. Perez-Mendez—O3
Knight, W. D.—J3
Kohler, D. and H. Hilton—M10
Kurti, N.—J1
Lambertson, Glen R., Bruce Cork, Oreste Piccioni, and William A. Wenzel—B9
Lander, Richard, William B. Fowler, and Wilson M. Powell—K2
Lannutti, Joseph E., Warren W. Chupp, Gerson Goldhaber, and Sulamith Goldhaber—O7
Lanou, R. E. and H. L. Kraybill—O5
Lauritsen, Thomas—N2
Lederhandler, S. R.—H2
Leland, W. T. and R. A. Olson—R5
Levin, E. R., D. B. Rosenblatt, and E. L. Offenbacher—F5
Loeb, L. B.—E4
Low, W.—S11
Loyd, C. M. and S. E. Hodges—P3
MacGregor, Malcolm H., William P. Ball, and Rex Booth—L8
Maenchen, George, William B. Fowler, Wilson M. Powell, and Robert W. Wright—K6
Mather, R. L.—C6
McConnell, Harden M. and C. H. Holm—S7
McKibben, J. L. and James Henshall—R4
Merkel, George—L9
Meyer, Donald I., Martin L. Perl, and D. A. Glaser—K4
Morris, G. J., R. K. Stitt, J. W. Keuffel, R. L. Call, and W. H. Sandmann—O1
Moszkowski, S. A.—G1
Mozley, R. F. and R. E. Taylor—B2
Nishimura, K. and M. Ruderman—I6
Noyce, R. N., C-T. Sah, and W. Shockley—H9
Omholt, A.—P4
Overley, J. C., R. E. Pixley, and W. Whaling—L3
Petroff, Michael D.—M3
Phelps, A. V.—E5
Pines, David—D2
Pollak, V. L. and R. E. Norberg—S9
Powell, D. A., H. S. Sellers, E. A. Milne, and E. C. Crittenden, Jr.—F1

Redfield, Alfred G.—S5
Rohatgi, Vijay K.—R6
Ruderman, M. A. and W. K. R. Watson—I1
Sah, C-T. and W. Shockley—H10
Sands, Matthew—Q1
Sandweiss, Jack and Maurice Goldhaber—K5
Sard, R. D., N. F. Harmon, M. Annis—K12
Schellenbaum, R. L.—C5
Schuman, R. P.—M8
Schwartz, C. L. and S. Gartenhaus—I5
Seifert, W. K. and D. H. Sloan—R3
Sellers, H. S., D. A. Powell, E. C. Crittenden, Jr., and E. A. Milne—F2
Shelton, Haywood—R8
Shockley, W. and R. N. Noyce—F7
Sill, R. C. and J. H. Miller—P5
Silsbee, H. B., W. A. Nierenberg, H. A. Shugart, and P. O. Strom—M2
Smith, Donald O.—S1
Smith, F. M., W. H. Barkas, W. F. Dudziak, P. C. Giles, H. H. Heckman, F. W. Inman, C. J. Mason, and N. A. Nickols—K9
Solmitz, F. T., L. W. Alvarez, H. Bradner, P. Falk, J. D. Gow, A. H. Rosenfeld, and R. D. Tripp—K1
Streib, John F.—Q2
Tautfest, G. W. and W. K. H. Panofsky—B3
Taylor, R. E. and R. F. Mozley—B1
Tomnovec, F. M.—M12
——— **and R. L. Mather**—C8
Uehling, Edwin A.—D3
Uretsky, J. L.—L5
van Rossum, L. and L. T. Kerth—K3
Warburton, F. W.—I12
Watson, Kenneth M.—D4
Watson, W. K. R., F. Zachariasen, and W. J. Karzas—I3
Wehner, G. K.—E1
Westberg, Russell G.—R7
Wheelon, Albert D. and Leon Blitzer—C2
Williams, W. S. C., K. M. Crowe, and R. M. Friedman—O6
Winans, J. G.—I11
Wong, Calvin, John D. Anderson, Calvin C. Gardner, and M. P. Nakada—L6
Woodyard, J. R.—R12
Wright, Robert W., Wilson M. Powell, George Maenchen, and William B. Fowler—K7

Preliminary Announcement of the 1957 Southwestern Meeting at Norman

The **1957 Southwestern Meeting** will be held in **Norman, Oklahoma,** on Friday and Saturday, **March 1 and 2, 1957.** The sessions will be held in the Oklahoma Memorial Union and the Research Institute—Physics Building of the University of Oklahoma. The banquet will be held Friday evening in the ball room of the Oklahoma Memorial Union.

Since a meeting in Oklahoma—which in 1957 celebrates its fiftieth anniversary of statehood—is a novelty for our Society, more information about living quarters are given here than is customary. Accommodations in Norman include the Lockett Hotel (one person $4.50; two persons $6.00, twin beds $6.50), Norman Courts (one person $4.50; two persons $6.00, twin beds $6.50), Extension Study Center, University of Oklahoma North Campus (double room with connecting bath, $1.75 per person; single room with community bath $1.50 per person). Reservations for any of these accommodations should be made as early as possible to Mr. F. Lee Hayden, Director of Conferences, University of Oklahoma, Norman, Oklahoma.

The following motels located on U. S. Highway 77 are recommended: OU Motel, El Nora Motel, Crown Motel, and Rail Fence Tourist Hotel. For persons wishing to stay in Oklahoma City, 18 miles north of Norman, the Biltmore and the Skirvin Tower hotels are recommended. Reservations at these hotels or motels should be made directly at an early date.

Norman city buses depart from the Extension Study Center, the Norman Courts and the Lockett Hotel for the Main Campus twice each hour. Buses leave Oklahoma City for Norman once or, at certain times of the day, twice each hour and reach the Norman bus station in 45 minutes. Five more minutes must be allowed to go by cab from the bus station to the University.

Norman is served by the Santa Fe railroad; Oklahoma City is served in addition by the Frisco, the Rock Island, and the MKT railroads. Persons traveling by air may take American Airlines, TWA, or Braniff Airways to Oklahoma City's Will Rogers Airport. University transportation to Norman will be available at a cost of $1.50 per person. Those desiring this service should write to Mr. F. Lee Hayden, Director of Conferences, University of Oklahoma, Norman, Oklahoma, informing him of time of arrival, airline, flight number, and where they will stay in Norman.

Deadline-date for this meeting is Friday, December 28, and abstracts of contributed papers are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

MEETINGS AND DEADLINES FOR THE SEASON 1956–1957

Place	*Meeting dates*	*Deadline date*
Monterey,* California	December 27–28–29	past
New York	January 30–February 2	past
Norman, Oklahoma	March 1–2	December 28
Philadelphia	March 21–23	January 18, 1957
Washington, D. C.	April 25–27	February 15
Notre Dame, Indiana	June 20–22	April 12
Boulder,* Colorado	September 5–7	to be announced

* Abstracts for the Boulder meeting are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmenbers whose papers are sponsored by members.*

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *Henceforth, if we receive an abstract typed on two pages, we shall print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

Proceedings of the American Physical Society

Minutes of the Fall Meeting of the Ohio Section of the American Physical Society, Held at Kent State University, Kent, Ohio, October 12–13, 1956

THE regular fall meeting of the Ohio Section of the American Physical Society was held at Kent State University, Kent, Ohio, on Friday and Saturday, October 12–13, 1956.

Friday afternoon was given to invited papers relating to the general subject "Solid State Physics," which were as follows. "The Electronic Structure of Solids—A Survey of Recent Theoretical Developments" by Dr. John R. Reitz, Case Institute of Technology, Cleveland, Ohio; "Physics and Chemistry of Phosphorus" by Dr. Manuel H. Aven, of the Lamp Development Laboratory, General Electric Company, Cleveland, Ohio; "Nuclear Magnetic Resonance Studies of Solids" by Dr. Dudley Williams, The Ohio State University, Columbua, Ohio; and "Recent Developments in X-Ray Spectroscopy of Solids" by Dr. Charles H. Shaw, The Ohio State University. This session was well attended with nearly one hundred in the audience. There followed a dinner in the Kent State Student Union, at which time Dr. Edward S. Foster, Jr., of University of Toledo spoke on "Material and Methods Needed for Training Men to Work in the Nuclear Energy Field."

Saturday morning was devoted to contributed papers, of which there were eight. The abstracts of the morning papers follow.

Leon E. Smith, *Secretary*
Ohio Section of the American Physical Society
Granville, Ohio

Sunshine and Shadow. Kenneth West, *Mt. Vernon, Ohio.*—This paper deals with an experiment by which a person almost completely untutored in astronomical matters can gain satisfactory knowledge of some of the details of the behavior of the earth and sun with reference to the direction of rays and shadows at any time of day, any day of the year, and at any location on the earth's surface. Sun-meridian time is used as a basis, though an equation of time graph is included. The experiment started with a simple peg board, which led by logical steps to a study of obelisks, pyramids, and to a proposal as to how the first gnomon-type horizontal sun dial was invented. The desire to understand these effects lead to the concept of the spherical nature of the earth, the tilt of its axis, and its orbit about the sun. Three designs of models to show the sun's direction at any time or place were produced. Conversely, these models will serve very well as sun dials. These models may not actually be new, but any good description of these particular ones are not readily found.

Efficient Use of a Picture Correlator. M. Horowitz, *Goodyear Aircraft Corporation.*—A picture correlator is a device which measures the amount of light passing through two photographic films as one slides past the other. It has been described by Kretzmer[1] in detail. Sufficient conditions have been found so that only 2 m readings instead of 6 are required to measure closely the coefficient of product-moment correlation between the transmissivities of two photographic films. These conditions are: (a) the pictures be black and white with the same ratio of black to white area; (b) the picture size be large compared to the image wavelengths; and (c) the pictures have the same scale. The two readings are made using a positive and a negative, rather than two positives. The value of the correlation coefficient in this case is $\rho=\Phi(0)-\Phi(\infty)/\Phi(\infty)$ where $\Phi(0)$ is the average transmissivity of the positive and negative in register and $\Phi(\infty)$ when completely out of register.

[1] E. R. Kretzmer, Bell System Tech. J. 31, 751 (1952).

Autocorrelation of the Earth's Crust with Analog Computer.* N. D. Diamantides and M. Horowitz, *Goodyear Aircraft Corporation.*—Correlation methods are employed in many fields of science and technology to derive statistical information.[1] As an example, analog computers were used to compute the autocorrelation functions of terrain profiles sampled from the earth's crust. Each profile was read out by a standard curve follower, the output was sampled by a commutator, and the autocorrelation values were registered in a bank of capacitors. This computing process required approximately 10 min/profile. For the two sample profiles considered—one near Akron, Ohio and the other near Phoenix, Arizona—the mean values of the terrain heights were 1200 and 1570 ft, respectively; and the rms relief values were 71 and 263 ft, respectively.

* Supported by the U. S. Air Force, Wright Air Development Command.
[1] W. Meyer-Eppler, VDI-Z 98, 600 (1956).

Information Theory and Terrain Classification.* A. A. Silvidi, F. L. Brooks, G. K. Schoepfle, K. L. Warren, *Kent State University,* and M. Horowitz *Goodyear Aircraft Corporation.*—A method of classifying the physical features of the terrain is presented. This method is based on obtaining the information content from topographical maps. Within certain limitations the statistical distribution of contour lines on a topographical map follows a Poisson's law. This makes the probabilities p_i (the probability that the value of ΔX_i, the range distance between contour lines, lies on the "ith" resolution range) dependent on only one parameter, the number n of contour lines. The information is then calculated using the formula

$$H_0=\sum_{i=0}^{\infty}(-p_i\log_2 p_i).$$

Additional information is present from the fact that each succeeding contour line can either increase, decrease one contour interval, or remain the same. To account for this, a simple arbitrary function $k(n)$ has been assumed and experimentally tested. The total information is then $H=H_0+k(n)$ and the information per nautical mile becomes $I=H/\langle\Delta X\rangle_{Av}$ where $\langle\Delta X\rangle_{Av}$ is the average number of ΔX's within any specified length of map. Hence, the information due to terrain features present in a map is determined by counting the number of contour lines. This scheme provides a quantitative method to classify the terrain. The terrain around Toledo, Ohio gives information of 8 bits/nm, while mountain regions around Marshall County, West Virginia have 47 bits/nm.

* Supported by the U. S. Air Force, Wright Air Development Command.

Angular Distribution of Fragments from the Photofission of U^{238}.* F. J. Milford, R. S. Shankland, J. D. Finegan,

AND Z. L. REINEKS, *Case Institute of Technology.*—Ilford and Eastman nuclear emulsions have been loaded with uranium acetate and exposed to an 18-Mev bremmstrahlung beam produced by the Case Betatron. These plates have been developed and then searched for fission tracks. A total of 1062 fission tracks has been measured to obtain the angular distribution of fission fragments. A least squares fit to the experimental data by a function of the form $F(\theta)=a+b\sin^2\theta+c\sin^2 2\theta$ gives $b/a=-0.0097$ and $c/a=0.0896$. The smallness of the $\sin^2\theta$ (or dipole) term is in agreement with results obtained by other workers.[1] The $\sin^2 2\theta$ (or quadrupole) term has not been previously reported. A simple model will be described which predicts such a term for photon wavelengths comparable with the nuclear diameter.

* Supported in part by the U. S. Atomic Energy Commission.
[1] E. J. Winhold and I. Halpern, Phys. Rev. **103**, 990 (1956).

Effect of the Use of Polaroid of Kodachrome Transparencies.* D. W. BOWMAN, *Bowling Green State University,* AND ARTHUR LANG, *Detroit Arsenal.*—Visually, Kodachrome transparencies involving green hues seem to show a color difference when exposed with and without the use of a polaroid filter. When examined in the spectrophotometer the difference seems to lie in the short wavelength transmittance minimum and maximum as compared to the central maximum. Spectrophotometer and tristimulus data correlate with the subjective appearance of the films. Spectrophotometric measurement of the transmittance of polaroid filters shows a fairly constant transmission over most of the visible region but a slight decrease below 450 mμ. This is enough to account for the shift in hue of the green transparencies which seems to be not dependent upon the polarizing effect.

* This research was conducted at the Applied Physics Laboratory of the Detroit Arsenal and supported by Ordnance Basic Research.

Research at the Van der Waals-laboratorium. STEFAN MACHLUP, *Western Reserve University.*—Using high pressure as a tool to explore molecular interaction, this laboratory is set up to investigate thermodynamic, optical, and transport properties of gases, liquids, and solids. The program, under the direction of Professor A. Michels, stresses high-precision measurement-temperatures known to 0.001°C, pressures to one part in 10^5 and concentrates on substances amenable to theoretical attack (e.g., rare gases). This report will attempt to share some impressions of a theoretical physicist's year in Amsterdam.

Ionization of Inert Gases by Positive Potassium Ions. DAVID E. MOE, *Western Reserve University.*—Ionization of the inert gases by relatively low-energy potassium ions has been investigated. The use of relatively intense ion beams and phase-sensitive detection of ionization signals yields a large increase in sensitivity over that obtained in former investigations. The enhanced sensitivity permits detection of ionization at lower ion energies than heretofore reported. The electron energy distribution of the ionization electrons has been determined from stopping potential curves and is found to be characteristic of the bombarded gas. In general, the energy distribution of the ionization electrons is independent of the incident ion energy.

Cumulative Author Index of Abstracts Appearing in this Volume of the Bulletin

Abashian, A.—343, 350
Abraham, Bernard M.—349
Abraham, M.—390, 396
Ackermann, R. J.—341
Acosta, A. J.—363
Adams, A., Jr.—144, 322, 322
Adams, E. N.—298
Adawi, I.—143
Adrian, F. J.—286
Aggson, T. L.—251
Aiello, W. P.—346
Akers, Lawrence K.—261
Albright, C. H.—194, 194
Albright, J. C.—91
Aldrich, L. T.—31, 31
Alers, Perry B.—116, 348
Alexander, Carl A.—270
Alger, R. S.—379, 379, 396
Allcock, G. R.—208
Allen, Leland C.—26
Allen, Robert C.—388
Allen, William A.—377
Allison, F. E.—115, 115
Allison, S. K.—28, 342
Allport, John—19, 360
Allred, W. P.—285
Almqvist, E.—30, 195, 195, 196
Alvarez, L. W.—385
Ament, W. S.—283, 293
Ames, Oakes—325
Amster, H. J.—194
Anderson, C. D.—251
Anderson, Carl E.—61, 68
Anderson, John D.—251, 376, 388
Anderson, Kinsey A.—229
Anderson, M. E.—84
Anderson, M. F.—255
Anderson, Norman G.—267
Anderson, T. H.—379, 379, 396
Anderson, V. C.—361
Andrew, Alan—254
Andrew, J. F.—297
Andrews, R. D.—122, 122
Annis, M.,—377, 386, 386
Antes, L. L.—279
Antonoff, George—293, 304
Ard, W. B.—200
Argyres, P. N.—298
Armstrong, A. H.—224, 296, 346
Aron, J.—293
Arp, V.—124
Artman, J. O.—283
Ascoli, G.—172
Ashby, V. J.—69
Ashkin, J.—72
Atkins, K. R.—218, 218
Atkinson, W. R.—98
Auer, Peter L.—26
Auerbach, L. B.—350
Augustyniak, W. M.—380
Aukerman, L. W.—332
Autler, S. H.—145
Awschalom, Miguel—31
Axelrod, N. N.—119
Ayres, R. U.—292
Babb, S. E., Jr.—91
Babiskin, Julius—58
Backman, Marvin E.—377
Baicker, J. A.—326
Bailyn, M.—300
Bair, J. K.—54, 264, 346
Baker, G. S.—139
Baker, James A.—178
Ball, J. B.—388
Ball, William P.—183, 388
Ballam, J.—185
Ballowe, William C.—230
Bame, S. J., Jr.—93
Banerjee, M. K.—194, 194
Banta, H. E.—70, 71
Baranger, Michel—209
Barber, S. W.—33
Barber, W. C.—387
Bardon, M.—212
Barkas, Walter H.—184, 186, 386, 386, 386
Barker, W. A.—11
Barnes, R. G.—11, 282, 282
Barnes, S. W.—174
Barr, E. Scott—258
Barr, William L.—389
Barredo, Joseph G.—85, 304
Barrett, A. H.—284
Barringer, R. L.—173, 173
Barth, Charles A.—14
Bartholomew, G. A.—28, 28, 29, 29, 39, 324
Bashkin, S.—211, 212, 212
Bass, Arnold M.—14
Batterman, B.—146
Beach, L. A.—10
Beams, J. W.—333
Bean, C. P.—133, 148
Beard, David B.—184, 184
Beauchamp, R. K.—346
Becker, J. H.—45
Becker, M. W.—331
Bedo, D. E.—225, 334
Beeman, W. W.—138
Beer, A. C.—54, 332
Belinfante, F. J.—46, 337
Bell, M. D.—127, 382
Bell, P. R.—70
Bell, R. E.—224
Bell, Stoughton, II—362
Bemski, G.—380
Benczer, N.—41
Bendel, W. L.—192
Benedek, G. B.—11, 124
Benedikt, E. T.—396
Bennett, F. D.—227
Bennett, R. A.—248
Bennett, R. G.—62, 296, 296
Bennett, Robert B.—244
Bennett, W.—68
Benson, K. E.—140
Bent, R.—212
Bents, U. H.—382
Benveniste, Jack—175, 175
Bergmann, Peter G.—208, 208, 221, 221
Bergstein, Leonard—133
Beringer, R.—68
Berko, S.—68, 339, 350,
Berkowitz, J.—202, 202, 341
Berley, David—320
Berlincourt, Don A.—132
Bernardini, G.—350
Bernstein, E. M.—41, 198
Bernstein, Jeremy—170
Berry, B. S.—139
Berry, Chester R.—141
Berry, R. Stephen—284
Bershader, Daniel—19
Bersohn, R.—215, 397
Bertozzi, W.—343
Beshers, D. N.—139
Betts, D. D.—255
Bevington, P. R.—198
Beyster, J. R.—176, 176, 194
Bichsel, H.—93
Biedenharn, L. C.—89, 89, 89
Bilaniuk, O. M.—326
Birchenall, C. E.—226
Birge, R. W.—184, 186
Birk, M.—344
Birkhoff, R. D.—184, 267
Blackman, Vernon H.—18
Blair, J. S.—20, 336
Blais, N. C.—281
Blankenbecler, R.—10
Blaser, J. P.—72
Blatt, F. J.—48, 114, 331
Bleuler, E.—29, 30, 134, 162
Blevins, M. E.—174, 177, 218
Blewitt, T. H.—130, 130, 130, 130
Blitzer, Leon—377, 377
Block, M. M.—36, 64, 174, 177, 186, 218
Block, R. C.—55, 62, 347
Bloembergen, N.—11, 124
Blok, J.—320
Blood, Howard L.—255
Bloom, S. D.—177
Blosser, H. G.—8, 224, 263
Blount, E. I.—143
Bloxsom, D., Jr.—362
Bludman, Sidney A.—51
Blum, Jacques M.—219
Blume, R. J.—397
Blumenfeld, H.—63
Bockelman, C. K.—223, 280, 296, 296
Boehm, F.—170, 170, 390, 390
Bollinger, L. M.—165, 187, 328, 347
Bolmgren, C. R.—339
Bolotin, H. H.—325
Bomelburg, Herbert J.—15
Bömmel, H. E.—57
Bond, C. D.—339
Bond, W. L.—111
Bondelid, R. O.—327, 328
Bonner, T. W.—20, 93, 94, 95, 96, 175, 324
Booth, E. T.—63
Booth, Rex—183, 388
Boothby, O. L.—132
Boreli, F.—326
Bortner, T. E.—263
Bostick, H. A.—252, 252
Bostick, Winston H.—166

Bostrom, N. A.—94
Bovarnick, Bennett—381
Bowe, J. C.—342
Bowers, R.—50
Bowker, J. K.—172
Bowman, D. W.—403
Bowman, J. C.—289
Braams, R.—201
Brabant, John M.—186, 251
Braden, C. H.—258, 264
Bradner, Hugh—174, 385
Bradshaw, B. C.—54, 54
Brady, J. J.—255
Bragg, J. K.—22
Braid, T. H.—344
Bramley, Arthur—286, 342
Brandt, Werner—219
Branscomb, Lewis M.—287
Branson, Herman—262, 266
Bratenahl, Alexander—178, 179, 179
Brattain, W. H.—293, 294
Braunstein, R.—126
Bray, P. J.—11, 215, 216, 323, 324
Bray, Ralph—114
Breit, G.—303
Breitenbecher, D. V.—279
Breslin, John P.—363
Bretscher, M. M.—164
Brewer, H. W.—26
Brice, M. K.—297
Brigman, George—393
Brink, G. O.—343
Brock, E. G.—279
Brockhouse, B. N.—188
Brockman, Karl W.—338
Brode, Harold L.—360
Brode, Robert B.—251
Brody, Richard H.—39
Broersma, S.—123
Broida, H. P.—13
Brolley, J. E., Jr.—9, 245, 246
Bromley, D. A.—30, 195, 195, 196
Bronstein, Leonard—33
Brooks, F. L.—402
Brooks, H.—48, 117, 300
Broudy, R. M.—331
Broyles, A. A.—27, 166
Brown, H. A.—23, 189
Brown, K. L.—376
Brown, L. M.—52
Brown, R. J. S.—216
Brown, S. L.—84
Brown, W. L.—48
Brown, William Fuller, Jr.—323, 323
Browne, Cornelius P.—212
Browne, M.—124
Brueckner, K. A.—181, 181
Brugger, K.—116
Brugger, R. M.—176
Brussel, Morton K.—338
Bryan, R. A.—230
Bube, Richard H.—110, 110
Buck, T. M.—294
Buck, W. L.—183
Buckingham, M. J.—177, 218
Bueche, A. M.—123
Buechner, W. W.—39, 212, 223, 223, 280
Bunker, M. E.—389
Burch, D. S.—287, 287
Bureau, A. J.—206
Burford, A. O.—260, 260
Burgy, M. T.—342
Burk, D. L.—119
Burnstein, R. A.—250
Burson, S. B.—329
Burstein, E.—126
Burton, B. S.—264
Buschert, R.—111, 340
Bushkovitch, A. V.—13, 302
Butler, C. P.—382
Butler, J. P.—187
Butler, J. W.—29, 40, 94, 163, 223, 327, 328
Button, K. J.—299
Byers, Cleo C.—97

Cable, J. W.—190
Cabrera, N.—140
Cady, D. W.—279
Caldwell, R. S.—126
Call, R. L.—391, 392
Callaway, Joseph—45, 258, 300
Callen, Earl—144
Callen, H. B.—24
Cameron, A. G. W.—191
Cameron, J. R.—324
Campbell, E. C.—183, 263
Campbell, George S.—364
Campion, P. J.—28, 324
Caretto, A. A.—224
Carleton, N. P.—228
Carlson, R. O.—49, 127, 128
Carlson, R. R.—211, 212, 212
Carnahan, Brice—292
Carter, R. S.—55, 204
Casabella, P. A.—215
Casella, R. C.—143
Caspari, M. E.—213
Casson, Harvey—56
Caswell, R. S.—347
Catron, Henry C.—188
Causey, C. W., Jr.—376
Chabai, Albert J.—19
Chaberski, A.—119, 297
Chambers, E. E.—10
Chandrasekhar, B. S.—133
Chang, David B.—250
Chang, Roger—129
Chang, W. Y.—186
Chapman, R. A.—95
Chapman, Seville—35
Chappelear, J. E.—98
Cheka, J. S.—184
Chen, D.—322
Chen, S. W.—327
Ch'en, Shang Yi—244
Cheng, Sin-I—19
Chernosky, Edwin J.—83
Chesnut, W. G.—9
Cheston, W. B.—339, 339, 384
Chew, G. F.—168
Chiba, Ren—326
Child, William C., Jr.—121, 121
Childress, James D.—189
Childs, William J.—342
Choppin, Gregory R.—8
Chretien, M.—185, 186, 349, 349
Christian, S. M.—126, 140
Christofilos, N. C.—290
Chuoke, Robert L.—98
Chupka, W.—202, 202, 341
Chupp, Warren W.—186, 392
Church, E. L.—180, 181, 330
Cimbleris, Borisas—68
Clark, C. B.—44
Clark, George W.—230, 230
Class, C. M.—20, 39, 88, 94
Clayton, Lorimer—341
Cleland, J. W.—135
Clement, J. D.—211, 326
Clifton, Donald F.—226
Coates, Robert J.—98
Coester, F.—194
Coffman, M. L.—90
Cohen, A. F.—8
Cohen, Alvin J.—136
Cohen, B. L.—8
Cohen, M. H.—143
Cohen, Victor W.—11
Cohn, H. O.—54, 175, 264, 346
Cole, F. T.—61, 178
Coleman, Bernard D.—32
Coleman, R. V.—204
Coles, B. R.—116, 300
Collins, C. B.—49, 127, 128
Collins, George B.—320
Collins, R. L.—216
Collins, T. L.—187
Coltman, R. R.—130, 130, 130, 130
Commins, E.—288
Compton, W. Dale—136
Condon, E. U.—218
Conn, William M.—34
Connors, D. R.—340
Conzett, Homer E.—253, 388
Cook, B. C.—63
Cook, C. Sharp—31, 253, 378
Cook, C. W.—191, 390
Cool, R. L.—173, 343, 350
Coomes, E.—333, 333
Coon, J. B.—90
Cooper, John N.—134
Copeland, Jack—265, 265
Corben, H. C.—181
Corbett, J. W.—334, 335
Corcos, G. M.—364
Corgan, J. M.—90
Cork, Bruce—186, 376, 376
Cork, J. M.—297, 329
Corliss, L. M.—190, 190
Corngold, Noel R.—11
Corrsin, S.—18
Corson, D.—59, 59
Corwin, Rudolph E.—255
Coté, R. E.—165, 187, 328, 347
Cotts, R. M.—282
Cox, S. A.—196
Cranberg, Lawrence—56, 175, 346, 346
Crandall, W. E.—225
Cranston, F. P.—389
Crasemann, Bernd—253
Crawford, F. S.—174
Crawford, G. W.—257
Crawford, J. H., Jr.—117, 135, 214
Crewe, A. V.—297
Crittenden, E. C., Jr.—379, 379
Cronin, J.—350
Cronin, James W.—20, 343
Crosbie, E. A.—209
Crouch, M. F.—176
Crowe, K. M.—392

Crownfield, F. R., Jr.—32
Cuevas, J.—28
Culpepper, L. M.—194
Cumming, J. B.—225
Cunningham, B. B.—396
Curtis, C. W.—141
Curtis, R. B.—52
Cutler, P. H.—279

Dabbs, J. W. T.—207, 207, 207
Dalgarno, A.—290
Damask, A. C.—147
Dance, W. E.—262
Danforth, W. E.—33
Dank, M.—33
Danos, M.—135, 246, 344
Darden, Edgar B., Jr.—267
Das, T. P.—215, 397
Daunt, J. G.—116
Davey, J. E.—396
Davidon, William C.—51
Davidson, Clifton R.—254
Davidson, N.—397
Davis, G. L.—31, 31
Davis, L., Jr.—144, 322
Davis, Monte V.—247
Davis, R. H.—324
Davis, Raymond, Jr.—219
Davis, W. H.—270
Davisson, T.—83
Day, R. B.—56
Dayhoff, Edward S.—283
DeBenedetti, S.—69
Dechand, C. O.—71
Delbecq, C. J.—124, 125, 324
deMars, G. A.—144, 322, 322
Demos, P. T.—343
Denney, J. M.—334, 335, 335
Denny, J. H.—334
der Mateosian, E.—207
de Saussure, Gerard—21
Desjardins, J. S.—63, 176, 177
DeSorbo, W.—31, 289, 334
Detenbeck, R. W.—344
Deutsch, M.—69, 69
DeWire, J.—59, 59
DeWitt, S.—67
Dexter, D. L.—112, 114, 119
Diamant, H.—131
Diamantides, N. D.—402
Dicks, J. B.—263
Dienes, G. J.—137
Dillinger, J. R.—349
Dillon, J. A., Jr.—53
Dillon, J. F., Jr.—125, 189
Dilmore, Betty Lou—258
Dinwiddie, J. F.—32
Dixon, J. R.—22
Doggett, J. A.—37
Dolan, P. J.—339
Dolloff, R. T.—33
Domen, S. R.—199
Donahue, D. J.—248, 248, 248
Donahue, T. M.—35, 202
Donnellan, J. E.—201
Donnelly, R. J.—57, 289
Douglas, R. A.—21
Downey, J.—21
Drachman, Richard J.—169
Drahmann, J. B.—379, 396
Draper, James E.—69, 290
Drechsel, Paul—121
Drell, S. D.—168, 383
Drenck, K.—131
Dresden, M.—58
Dresselhaus, G.—143
Dreyfus, Russell W.—140
Dropesky, B. J.—162
Drougard, M. E.—191
Drummond, J. E.—244
Dubey, V. S.—42, 164
Dudley, John M.—182
Dudziak, Walter F.—174, 386, 386, 386
Duffield, R. B.—206
Duga, J. J.—332
Dulit, E. P.—69, 69
DuMond, Jesse W. M.—170, 170, 219
Duncan, M. M.—17
Dunlap, W. C., Jr.—294
Dunning, K. L.—327

Earl, J.—230
Easterday, H. T.—253
Eastwood, T. A.—187
Ebel, M. E.—303, 303
Ecker, G.—87, 166, 166
Edelsack, E. A.—325
Edwards, R. R.—171
Edwards, Ray L.—270
Efremov, N.—293, 203
Ehlers, Kenneth W.—61
Ehlert, Ralph C.—327
Ehrlich, Gert—291, 291
Ehrenreich, H.—48, 332
Einbinder, Harvey—203
Eisberg, R. M.—19, 181
Eisen, F. H.—226
Eisner, E.—222
Eisner, M.—92, 92
Ekspong, G.—186
Ekstein, H.—25, 65, 66
Elliott, N.—190, 190
Ellis, A. T.—363
Ellison, R. D.—207
Elsasser, Walter M.—83
Elton, L. R. B.—170
Elwyn, A. J.—281
Emmerich, W. S.—194, 195
Emrich, Raymond—19
Endt, P. M.—223
Enge, H. A.—212
Engelkemeir, D. W.—171, 171
English, W. N.—249, 249
Enoch, J.—168
Erickson, G. W.—339, 339, 384
Erickson, R. A.—217
Evans, A. E., Jr.—279
Evans, J. E.—176, 247, 247, 247, 327
Everett, A.—329
Everhart, E.—292
Ewald, A. W.—226
Ewan, G. T.—330

Fabricand, B. P.—225
Fafarman, A.—65
Fagg, L. W.—165
Fain, B. W.—84
Fain, Janice—9
Fairbank, William M.—177, 217, 218, 218
Fairhall, A. W.—388
Falk, D. S.—60
Falk, E. D.—255
Falk, P.—385
Falkoff, D. L.—65
Famularo, K. F.—9, 339
Fan, H. Y.—111, 126, 126, 331
Faneuff, C.—34, 34, 201
Fang, P. H.—38
Farnsworth, H. E.—45, 53
Farwell, G. W.—20
Fawcett, E.—217
Feder, R.—129
Feenberg, E.—209
Ferguson, A. J.—180
Feher, G.—125, 125
Feinberg, Gerald—169
Feiner, F.—72
Feingold, Arnold M.—181
Feld, Bernard T.—72
Feldman, David—51
Feldmann, W. L.—295
Fenstermacher, C. A.—62, 296, 296
Ferrell, Richard A.—16, 17, 17, 44, 44, 44, 138, 217
Ferry, John D.—121, 121, 123
Feshbach, Herman—36, 195
Fields, P. R.—281
Fields, T. H.—71, 71
Filosofo, I.—350
Fincher, H. A.—339
Finegan, J. D.—402
Fink, Richard W.—40, 171, 171
Finkelstein, David—166, 208
Fireman, E. L.—343, 344
Fischer, Fred W.—250
Fischer, P. G.—302
Fiske, M. D.—334, 335
Fitch, John L.—92, 92
Fitch, V.—185
Fitz, Harold C., Jr.—86
Fletcher, R. C.—125, 125
Fluharty, R. G.—247, 247
Flynn, John M.—291
Foland, William D.—268
Folen, V. J.—132, 132
Foner, S.—117, 298, 299
Fong, Peter—303
Fonger, W. H.—135
Ford, G.—195, 195
Ford, W. K., Jr.—333
Foster, Howard J.—262
Fournet, D.—64, 185
Fowler, A. B.—294
Fowler, E. C.—71
Fowler, J. L.—175
Fowler, J. M.—325
Fowler, R. G.—98
Fowler, William A.—191, 391
Fowler, William B.—385, 386, 386, 392
Fox, George R.—141
Fox, J. G.—9, 71
Fox, R. E.—288
Fox, T. G.—123
Frankel, S.—171
Franklin, Jerrold—169
Frauenfelder, H.—163
Frederikse, H. P. R.—298
Freedman, M. S.—171
Freeman, A. J.—198
Fregeau, J. H.—9
Freidstadt, Hans—47
Freier, G. D.—9, 339

Freier, P. S.—219, 230
Freiser, M. J.—349
French, J. B.—223
Fretter, W. B.—251
Friauf, Robert J.—145
Friedberg, S. A.—117, 119, 147
Friedlander, G.—224, 225
Friedman, A. M.—281
Friedman, M. H.—168
Friedman, R. M.—392
Friedman, Robert H.—90
Friesen, W. J.—8, 248, 249, 249, 344
Früchtenicht, Joseph—329
Fritts, R. W.—226, 333
Frost, L. S.—288
Fry, W. F.—64
Frye, Glenn M., Jr.—93, 196
Fukuda, Nobuyuki—181, 337
Fuller, E. G.—21
Fuls, E. N.—292
Fulton, C. D.—217
Fulton, Thomas—25, 66
Furth, H. P.—191, 226
Fuson, Nelson—259
Futch, A. H., Jr.—22

Gaertner, E. R.—8
Gallagher, C. J.—128
Gallaher, L. H.—271
Gallaher, L. J.—135
Gallet, Roger—228
Galli, M.—231
Galonsky, A.—180, 196
Galt, J. K.—321
Galvin, James A.—179
Gammel, Juanita H.—196
Gardner, Calvin C.—175, 175, 388
Garrett, C. G. B.—293, 294
Gartenhaus, S.—383, 383
Garth, R. C.—61
Garwin, Richard L.—61
Gasten, B. R.—21, 326
Gatchell, E. K.— 297
Gates, Duane C.—376
Gaynor, Joseph—292
Geballe, R.—287, 287
Geballe, T. H.—117
Gebbie, H. A.—145
Geer, E. H.—165, 196, 197, 211, 211, 325, 325
Geffen, D. A.—46
Geib, I. G.—111, 340
Geiger, J. S.—284
Gelernter, H.—37
Geltman, Sydney—222
Genser, M.—285
George, W. D.—387
Gerhart, J. B.—195
Gerstein, G.—192
Gersten, R.—375
Ghosh, S. N.—27, 202
Giacomelli, G.—174
Gibbons, J. H.—62, 71, 71
Gibbons, M. D.—279
Gibbons, Mathew G.—378
Gibbs, Peter—137
Gibson, J. B.—147
Gifford, F.—333
Gilbert, Francis C.—185
Gilbert, T. L.—25, 189
Gildart, Lee—226
Giles, P. C.—386, 386, 386
Gilman, J. J.—348
Gilmore, F. R.—363
Gindler, J. E.—171
Girifalco, L. A.—31
Gittelman, B.—69, 69
Glaser, D. A.—385
Glaser, Walter—84
Glasgow, Lyle E.—254
Glashow, S.—180
Glasser, R. G.—230, 320
Glassgold, A. E.—180, 339, 339, 384
Gobeli, G. W.—134
Goebel, Charles J.—52
Goland, A. N.—226
Gold, L.—214
Goldberg, Colman—53
Goldberg, Irwin—208
Goldberg, N.—207, 291
Goldhaber, Gerson—186, 392, 392
Goldhaber, Maurice—207, 385
Goldhaber, Sulamith—186, 392
Goldman, D. T.—17
Goldman, J. E.—147, 148
Goldring, B. G.—282
Goldsmith, George J.—322
Goldstein, B.—145
Goldstein, J. H.—260
Goldstein, Martin—109
Gobeli, G. W.—111
Goldstine, H. H.—210
Gonser, U.—299
Good, M. L.—174
Good, R. H., Jr.—279
Good, W. M.—71, 71
Good, William B.—260
Goodman, Charles D.—41, 193, 224
Goodman, Leonard S.—342
Goodrich, Max—264
Goodwin, Aurel, Jr.—251
Gordon, M. M.—269
Gordon, R. B.—136
Gordy, Walter—199, 200, 200, 200, 215, 266, 267, 267
Gorman, R. L.—204
Goss, A. J.—140
Gossett, C. R.—40, 95, 163, 223
Gossick, B. R.—144, 322
Gottfried, K.—194
Gottlieb, Milton—112
Gould, F. T.—69, 70
Gould, Roy W.—35
Gourary, B. S.—286
Gove, H. E.—28, 29, 29, 30, 39, 180, 195, 195, 196
Gow, J. D.—385
Grad, H.—18
Graetzer, H. G.—280
Graham, R. L.—68
Graham, Walter J.—394
Grant, F. A.—22, 22
Green, Alex E. S.—16, 16, 269, 269
Green, M. S.—338
Green, Milton—227
Greenberg, J. Mayo—66
Greene, John M.—51
Greene, L. C.—111
Greider, Kenneth R.—376
Greyber, H. D.—245
Griffing, G. W.—290
Grimes, D. M.—25
Grimm, G.—63, 176, 176, 177
Grodzins, L.—163, 164, 329
Groetzinger, G.—58
Groseclose, B. C.—350
Gross, B.—121
Gross, E. P.—216, 227
Grossman, J. J.—396
Grossman, L. M.—363
Groves, Steven—271
Grundl, J. A.—95
Guentert, Otto—138
Gullikson, C. W.—90
Gunther-Mohr, G. R.—119
Gupta, Ishwar C.—186
Guth, Eugene—21, 36, 183
Guthrie, G. L.—147, 148
Gutmann, Felix—381
Gutzwiller, M. C.—86

Haake, C. H.—113
Haas, George A.—395
Haber-Schaim, U.—168, 172
Haeberli, W.—62, 212, 213
Hafner, E. M.—9
Hagedorn, F. B.—387
Hahn, E. L.—397
Hakeem, M. A.—264
Halbert, M. L.—193
Haling, R. K.—29
Hall, George L.—140
Hall, H. E.—96
Hall, R.—63, 64
Hallett, A. C. Hollis—289
Halpern, F. R.—383
Halpern, I.—388
Halpern, J.—192
Halsted, R. E.—321
Ham, F. S.—114
Ham, Joe S.—121
Hamermesh, Bernard—189
Hamermesh, M.—209, 303
Hamlen, R. P.—215
Hammer, C. L.—206
Handin, J. W.—87
Handler, P.—144
Handley, T. H.—193, 224, 263, 330
Hanna, S. S.—329
Hans, H. S.—55
Hansen, L. F.—251
Hanson, A. O.—350
Hanson, H. P.—83, 199
Hanson, Harold P.—138
Hanson, Howard G.—22
Happ, W. W.—382
Harada, R. H.—39
Harleman, Donald, R. F.—18
Harman, George G.—112
Harmatz, B.—330
Harmon, N. F.—377, 386, 386
Harris, I.—52
Harris, J. C.—134
Harris, Mark—69
Harrison, S. E.—24, 24, 189
Harrison, Walter A.—142
Harth, E. M.—36, 64, 174, 177, 186, 218
Hartman, C.—394
Harvey, J. A.—187, 347
Hassler, F. L.—280
Hastings, J. M.—190, 190
Hatch, Albert J.—342
Hatch, E. N.—170, 170, 390, 390

Hatcher, John R.—265
Haughton, Paul F.—265
Haugsnes, Jack—187
Hausman, H.—56
Havas, Peter—337
Havens, W. W., Jr.—62, 63, 69, 176, 176, 177, 212
Hawgood, John—222
Haxby, R. O.—192
Haynes, S. K.—260, 260, 260
Hayward, E.—21
Hayward, R. W.—42
Heaps, C. W.—87
Heath, D. F.—13
Heckman, Harry H.—184, 186, 386, 386, 386
Hedges, Richard M.—394
Heer, C. V.—217
Hegyi, I. J.—213
Heikes, R. R.—190
Hein, R. A.—218, 289
Heinberg, Milton—168
Heine, V.—381
Heller, W.—123
Helmer, R. G.—297
Hemmendinger, A.—96
Hemstreet, H. W.—88
Henderson, J. W.—204
Hendrick, Roy W., Jr.—35
Hendrickson, T. J.—24
Henke, B. L.—34, 34
Henkel, John H.—258
Henkel, R. L.—346
Henley, E. M.—20, 384
Hennig, Gerhart R.—119
Henri, V.—185
Henry, R. R.—96, 96, 96
Henry, Warren E.—217, 289
Henshall, James—394
Henshaw, D. G.—63, 68
Hensley, E. B.—286
Henvis, B. W.—126
Herbstreit, J. W.—228
Hereford, F. L.—339
Hernandez, H. Paul—178
Herndon, John A.—259
Herring, C.—117
Herring, D. F.—326
Herring, J. R.—222
Herrmann, Gabriel—13
Hersh, Herbert N.—213
Herzfeld, C. M.—58
Hewitt, R. R.—283
Heydenburg, N. P.—43, 164
Hibdon, Carl T.—346
Hickmott, T. W.—291
Hicks, Donald A.—8
Higgs, D. V.—87
Hildebrand, R. H.—72
Hildebrandt, A. F.—92
Hill, D. E.—321
Hill, D. L.—384
Hill, R. W.—174
Hiller, Robert E.—259
Hilton, H.—390
Hinds, Conrad—262
Hino, J.—150, 150
Hintz, N. M.—181, 327
Hirschfelder, Joseph O.—203
Hisatake, K.—163, 271, 134
Hoang, T. F.—64, 320
Hodges, S. E.—393
Hofmann, J. A.—148, 148
Hoffman, John D.—110
Hofstadter, R.—10, 10
Hogan, R. S.—111
Holladay, W. G.—51, 269
Holland, Dan H.—169
Holland, Robert E.—327
Holm, M. W.—70
Holm, C. H.—397, 397
Holmes, D. K.—130, 130, 130, 135
Holmes, John R.—39
Holmgren, H. D.—21, 21, 29, 40, 134, 163, 196, 197, 211, 211, 223, 325, 325
Holmquist, Fred N.—392
Holt, N.—70
Hood, Donald W.—261
Hooks, B. W.—393
Hopkins, J. C.—162
Hopkins, J. I.—263
Hoppes, D. D.—42
Hornig, James F.—203
Horning, W. A.—248
Hornyak, W. F.—197, 197, 231
Horowitz, M.—402, 402, 402
Horton, G. K.—255
Horwitz, N.—225
Horwitz, Nahmin—186
Hosler, W. R.—298
Hough, P. V. C.—290
Householder, A. S.—210
Houston, J. M.—301
Hrostowski, H. J.—111, 295
Huang, Kerson—222
Hubbell, H. H.—184
Hubbell, H. H., Jr.—267
Hubbs, J. C.—252, 253, 343, 343
Hubert, P.—165
Hudis, J.—224
Hudson, A. M.—389
Hudspeth, E. L.—94
Hughes, D. J.—8, 55, 61, 187, 188, 204, 347
Hughes, D. S.—99
Hughes, F.—137
Hughes, Floyd L.—113
Hughes, V.—68
Hughes, V. W.—284
Huibregtse, E. J.—50, 50
Huizenga, J. R.—43, 171
Hungerford, H. E.—261
Hurlbut, Franklin C.—361
Hurst, G. S.—263
Hutchison, Dwight A.—288
Hutchinson, F.—200, 201
Hutson, A. R.—144, 381
Hwang, C. P.—217

Igo, G.—21, 384
Imhof, W.—173, 392
Inchauspé, Nicolas—206
Inghram, M. G.—202, 202, 341
Inman, Fred W.—182, 386, 386, 386
Inn, Edward C. Y.—382
Innes, F. R.—302
Ise, John, Jr.—8
Ivash, E. V.—84

Jablonski, F. E.—70
Jackson, E. A.—227
Jacobs, J. A.—212, 212
Jaffe, Hans—132
Jahn, Robert G.—228
James, H. M.—349
Janis, Allen—208
Jarmie, Nelson—28, 388
Jastram, P. S.—172
Jauneau, Louis R.—392
Jeffries, C. D.—390, 396
Jen, C. K.—12
Jenkins, F. A.—389
Jenkins, T. L.—167
Jenkins, Thomas L.—376
Jennings, B.—55
Jenny, D. A.—111
Jensen, John T., Jr.—395
Jensen, R. V.—140
Jentschke, W.—193
Johns, M. W.—42
Johnson, C. H.—261
Johnson, D. S.—18
Johnson, F. M.—283
Johnson, J. R.—120
Johnson, Leo F.—127
Johnson, O. E.—162
Johnson, Peter D.—113
Johnson, R. G.—162
Johnson, R. M.—184, 267
Johnson, V. A.—120, 332
Johnson, W. H., Jr.—343
Johnsrud, A. E.—56
Johnston, R. L.—134, 196, 197, 211, 211, 325, 325
Johnston, Richard—21
Johnston, W. G.—348
Joki, E. G.—176, 247, 247
Jona, F.—131
Jones, Ernest A.—259
Jones, James T.—134, 271
Jones, K.—212
Jones, K. W.—326
Jones, M. E.—187
Jones, P. R.—292
Josien, Marie-Louise—259
Joyner, W. T.—280
Judish, J. P.—70, 261
Jung, R. G.—172
Jungerman, J. A.—184
Juretschke, H. J.—54
Juveland, A. C.—193

Kabir, P. K.—46
Kadaba, P. K.—265
Kadyk, John A.—251
Kahn, Arnold H.—129
Kaiser, H. F.—179
Kaiser, R. H.—295
Kaiser, W.—321
Kalbach, R. M.—250, 375
Kalmbach, S. H.—393
Kammer, E. W.—115, 257
Kane, Evan O.—49, 127, 285
Kane, J. A.—9, 71
Kane, J. V.—171
Kanter, Manuel A.—119
Kaplan, D. E.—397
Kaplan, Jerome I.—24
Kaplan, Joseph—14
Kaplan, Paul—363
Kaplan, Selig N.—376
Kaplon, M. F.—64, 320
Karal, Frank J.—92

Kardon, Samuel—121
Karrer, S.—226, 333
Karzas, W. J.—383
Kasner, W. H.—202
Kasper, J. E.—230
Kassner, James L., Jr.—260
Kassner, R. R.—177
Katzman, John—319
Keck, P. H.—321
Kedzie, R. W.—390, 396
Keeling, R. O., Jr. —138
Keller, J. M.—24
Kelley, G. G.—70
Kellogg, Paul J.—73
Kelly, Howard R.—250
Kendall, H.—164
Kendall, J. M.—362
Kendrick, Nisbet S., Jr.—257
Kennedy, Anthony—142
Kennedy, W. L.—337
Kenney, Robert W.—182, 251, 251, 376, 389
Kenney, V. P.—71
Kenny, P. J.—339
Kepler, R. G.—251
Kerlee, D. D.—20
Kerner, Edward H.—202, 338
Kerth, L. T.—385
Kessler, J. O.—140
Kessler, K. G.—22
Kestin, J.—364
Keuffel, J. W.—391, 392
Keyes, R. J.—299, 299
Khuri, N. N.—52
Kieffer, L. J.—13
Kikuchi, Ryoichi—133
Kilb, Ralph W.—197, 198
Kilkson, Rein—200
Kim, Y. B.—375
Kindall, S. M.—261
Kinderman, E. M.—62, 248
King, D. T.—173
King, Jean I. F.—222
King, R. F.—70, 261
King, R. W.—16
King, Rutledge F.—70
Kington, J. D.—54, 264
Kinsinger, J. B.—121
Kip, A. F.—124
Kistner, O. C.—30
Kittel, C.—124
Kjeldaas, T.—116
Klarmann, J.—230
Klein, Walter—69
Klema, E. D.—85
Klemperer, William—284, 284
Klick, C. C.—112
Klick, Clifford—112
Knapp, E.—173, 392
Knight, W. D.—124, 283
Knowles, J. W.—330
Knox, R. S.—112
Kobayashi, Koichi—32
Koch, H. W.—10, 199, 284
Koch, Robert—94
Koehler, J. S.—114, 115, 138, 139, 204
Koehler, W. C.—190
Koenig, S. H.—119
Kohler, D.—390
Kohn, W.—116, 125
Kolb, Alan C.—22
Kolm, H. H.—145, 298, 299
Korringa, J.—216
Koshiba, M.—229
Kosiba, W. L.—137
Koski, W. S.—215
Kostkowski, Henry J.—14
Kovacs, Julius—337
Krahn, E.—365
Kraichnan, Robert H.—341
Krasner, S.—28
Kraus, Alfred A., Jr.—20, 94, 94, 211
Kraus, O.—215
Kraushaar, W. L.—230
Kraybill, H. L.—71, 296, 392
Kreger, H. H.—325
Kriessman, C. J.—24, 24, 189
Krimm, S.—109
Kroemer, H.—143
Krohn, V. E.—43, 176, 330
Krone, R. W.—212, 329
Krumhansl, J. A.—117, 289
Kruse, P. W.—205
Kruse, T.—212
Kruse, T. H.—326
Kruse, U. E.—297
Krzywoblocki, M. Z. v.—18, 338
Kunkel, Wulf B.—361
Kunz, F. W.—128
Kunz, W. E.—29
Kuper, Alan B.—149
Kurath, D.—180
Kubatov, J. D.—134, 163, 271
Kurland, Robert J.—12
Kursunoglu, Behram—46
Kushida, T.—11, 124
Kyropoulos, S.—396

Lad, R. A.—31
Lafferty, D. L.—260
Lafferty, Donald L.—261
Lagemann, Robert—265
Laitone, E. V.—73, 361
Lamarsh, John R.—36
Lambe, John—112
Lambertson, Glen R.—376
Lampert, Murray A.—27, 128
Lancaster, F. W.—32
Landauer, J. K.—205
Landauer, R.—191
Lander, Richard—385
Landes, H. S.—68
Lang, Arthur—403
Lang, G.—69
Lang, H. J.—346
Landon, H. H.—347, 347
Landweber, L.—363
Landwehr, George—284
Lane, R. O.—187, 346
Langer, L. M.—162
Lanning, D. D.—248, 248, 248, 248
Lannutti, Joseph E.—186, 392
Lanou, R. E.—392
Laponsky, A. B.—279, 279
Larach, S.—213
Lark-Horovitz, K.—111, 331, 332, 340
LaRocque, Armand P.—167
Larson, H. V.—244
Larsson, K. E.—182
Laslett, L. J.—61, 178
Last, Jay T.—255
Laufer, John—227, 362
Lauritsen, C. C.—191
Lauritsen, T.—191
Laurmann, John A.—364
Lavine, Jerome M.—23
Lawson, R. D.—17, 17, 17, 245, 246
Lax, Benjamin—48, 117, 117, 299, 299
Lax, Melvin—87, 128
Lazar, N. H.—163
Lazarus, David—149, 150
Leach, W. F.—87
Leadon, Bernard M.—365
LeBlanc, J. M.—165, 187
Lebowitz, Joel L.—73, 221
LeCraw, R. C.—23
Leder, Lewis B.—43, 166
Lederhandler, S. R.—381
Lederman, L. M.—63, 72, 174
Lee, Kiuck—16
Lee, Lieng-Huang—292
Lee, L. L., Jr.—281, 327
Lees, Lester—360, 362
Lefevre, H. W.—62, 248
Leffert, C. B.—202
Lehmann, W.—113
Lehmann, William L.—271
Leichter, M.—134
Leighton, R. B.—251
Leinhardt, T. E.—88
Leiss, J. E.—197, 199, 284
Leite, Richard J.—14
Leitner, J.—185, 186, 349, 349
Leivo, W. J.—127, 382
Leland, W. T.—388, 395
Leonard, B. R., Jr.—8, 248, 249, 249 344
Leonard, Stanley L.—167
Leveque, A.—280
Levin, E. R.—380
Levin, Jules S.—56, 175, 346
Levine, M. A.—191
Levine, N.—163
Levine, Sidney—255
Levinger, J. S.—37, 84, 269
Levinson, C. A.—194, 194
Levinstein, H.—137, 226
Levi-Setti, R.—319, 320
Levy, Paul W.—136, 140
Lewis, D. R.—87
Lewis, H. W.—41, 212, 213, 280
Lewis, R. R.—195, 195
Li, Huon—363
Liang, C. Y.—109
Lichtenberg, D. B.—51, 337, 344
Lichtenstein, P. G.—184
Lide, David R., Jr.—13, 198
Lidiard, A. B.—145
Lidofsky, L.—212
Lidofsky, L. J.—326
Liepmann, H. W.—364
Lievo, W.—141
Likely, J. G.—339
Lin, Chun Chia—13, 197, 198
Lin, Lan-Ying—213
Lind, D. A.—56
Lind, Edward L.—110, 110
Lindeberg, G. K.—185
Linden, Bernard R.—199, 301
Linder, M.—41
Lindner, M.—41
Ling, F. F.—34
Linsley, J.—230

Lipps, F. W.—167
Lipson, H.—299
Lipworth, E.—253
Litherland, A. E.—28, 29, 29, 30, 39, 195, 195, 196
Littlejohn, C. S.—342
Livingston, R. S.—60
Lloyd, Joseph P.—92
Lockenvitz, A. E.—84
Lockwood, J. A.—36
Loeb, L. B.—379
Loebner, E. E.—119
Loeffler, F. J.—350
Loferski, J. J.—111, 135
Lokken, J. E.—249, 249
Long, T. R.—205
Lord, N. W.—12
Lord, J. J.—250, 250, 375
Lovell, Robert J.—259
Low, W.—283, 398
Loyd, C. M.—90, 393
Luckey, D.—59, 59, 172
Ludwig, G. H.—230
Lulay, John—150
Luttinger, J. M.—125

MacGregor, Malcolm H.—183, 188, 388
Machlup, Stefan—403
Mack, S. F.—362
Mackenzie, D. R.—330
Mackliet, C. A.—150
Macklin, R. L.—62, 264
MacMillan, D. B.—188
Maczuk, J.—225
Madden, H. H.—53
Maeder, P. F.—364
Maenchen, George—386, 386
Magleby, E. H.—327
Magnusson, L. B.—171
Major, F. G.—336
Malenka, B. J.—169, 209
Malich, C. W.—43
Malitson, I.—214
Malkin, M. S.—68
Maltrud, H. R.—162
Mann, D. E.—198
Mann, L. G.—41
Mandel, M.—284
Mandelkern, Leo—110, 123
Mandeville, C. E.—39, 42, 164
Marcus, Paul M.—44, 142
Margenau, H.—295
Margolis, Bernard—66, 336
Marinace, J. C.—294
Marion, J. B.—20, 94, 95
Marion Jerry B.—94, 196, 210
Mark, Hans—17, 17, 17, 245
Markley, F. W.—192
Markham, Jordan J.—286
Markowitz, Samuel S.—224
Marmier, P.—170, 170
Marshak, H.—62
Marshak, R. E.—37
Marshall, J. F.—33, 38
Marshall, S. A.—133
Martens, F. H.—68
Martin, D. W.—329
Martin, G. M.—123
Martin, R.—59, 59
Marton, L.—14, 43, 43, 167, 301
Mason, C. J.—386, 386, 386
Mast, C. B.—180
Mather, R. L.—183, 378, 378
Mathews, F.—64
Matossi, Frank—38
Matsen, F. A.—90, 91, 91, 393, 394
Mattingly, James T.—389
Maunsell, C. D.—249, 249
Maurer, R. D.—348
Mavroides, J. G.—117
Maxwell, L. R.—23
Mayer, J.—322
Mayfield, Earle B.—377
Mayo, James W.—262
Mazari, M.—212
Mazzi, F.—131
McClellan, L. W.—247
McClellan, Robert—227, 362
McClure, J. W.—119, 255
McCombie, C. W.—145
McConnell, Harden M.—397, 397
McCormac, B. M.—339
McCormick, Gene—200
McCrary, J. H.—95
McCraw, T. F.—43
McDaniel, B.—59, 59
McDonald, Charles A.—251
McDonald, Charles A., Jr.—376
McDonald, F. B.—230
McDonald, Marcia—149
McElhinney, J.—340
McElhinney, John—192, 192
McGowan, F. K.—164, 164, 264
McGrath, J. W.—270
McGrew, C. G.—185
McGruer, J. N.—325
McGuire, T. R.—23
McHale, J. L.—89, 89, 89
McIntyre, R. J.—137
McKelvey, J. P.—225
McKeown, M.—206
McKibben, J. L.—61, 394
McKim, F. S.—294
McLean, E. A.—34, 34, 201
McLeod, B. A.—53
McManus, H.—56
McMillan, D. E.—8
McReynolds, A. W.—133
McSkimin, H. J.—57, 111
McVoy, Kirk—51
McVoy, Kirk W.—183
McWhorter, A. L.—145
Mebane, Banks H.—209
Medved, D. B.—54
Meechan, C. J.—129
Mehlhorn, H. A.—56
Meiklejohn, W. H.—148
Melkonian, E.—62
Melnick, Donald A.—22
Melvin, M. A.—67, 74
Mencher, A.—11
Mendlowitz, H.—37
Merat, Parviz—208
Mercereau, J. E.—12
Merkel, George—388
Merritt, F. R.—321
Merzbacher, E.—26, 222
Metropolis, Nicholas—210
Metzger, Franz R.—40, 211
Meunier, R.—173, 173
Meyer, Donald I.—385
Meyerott, R. E.—26
Michel, R. E.—215
Midgley, J. E.—346
Mielczarek, S. R.—14, 301
Mihelich, J. W.—206, 330, 330
Milani, S.—134
Milford, F. J.—402
Millburn, George P.—376
Miller, J. H.—393
Miller, James—90
Miller, John E.—257
Miller, L. G.—247, 327
Miller, P. H., Jr.—120, 120
Miller, R. C.—167
Miller, S. C., Jr.—98
Miller, W. C.—340
Miller, W. F.—202
Milligan, W. O.—87
Milne, E. A.—379, 379
Mills, C. B.—279
Mills, W. R.—8
Minden, H. T.—39
Mink, H. Ray—259
Miskimen, J. T.—270
Mitchell, D.—226
Mitchell, F. H.—265, 265
Mitchell, R. W.—92
Mitchell, T. P.—361
Mittleman, M. H.—46
Mize, J. P.—171, 389
Moak, C. D.—196, 261
Mobley, R. C.—261, 179
Moe, David E.—403
Monahan, J. E.—56, 187, 346
Montgomery, D. J.—205
Montgomery, H. C.—53
Moore, H. A.—269
Moore, M. N.—221
Moore, M. S.—39, 88, 163, 327, 327
Mooring, F. P.—56, 281, 327
Morgan, H. W.—260
Morgan, Ira Lon—94, 96
Morgan, L. O.—92
Morinaga, H.—30, 162
Morowitz, Harold J.—201
Morris, G. J.—391, 392
Morris, T. F.—47
Morrish, A. H.—322, 323, 323
Morrison, Harvey L.—377
Mosburg, E. R.—71
Moseley, H. M.—60
Moszkowski, Steven A.—16
Motz, J. W.—10
Moyer, Burton J.—185, 186, 252, 252, 376
Mozer, F.—191
Mozley, R. F.—375
Mrozowski, S.—118, 118, 119, 297, 300
Muchmore, R. B.—228
Muether, H. R.—55
Mukerji, Ambuj—21
Mullin, C. J.—180
Mullins, Roy K.—179
Munick, R. J.—302, 321
Murphy, P. G.—28, 325
Murray, Joseph J.—186, 225
Murray, R. B.—296
Musa, R. S.—97
Myers, Ira T.—246

Nablo, S. V.—42
Nakada, M. P.—69, 388
Nakada, M. Paul—175, 175
Nakagaki, M.—123
Nanney, C.—34
Naugle, J. E.—230
Naugle, John—219
Naumann, R. A.—42
Neddermeyer, S. H.—244
Need, John L.—41, 193
Neely, H.—129
Neiler, J. H.—70, 71, 71
Nelkin, M. S.—188
Nelson, C. M.—214
Nelson, Edward B.—329
Nesbet, R. K.—24
Nethercot, A. H., Jr.—13, 283
Nettleton, R. E.—338
Neuer, J. R.—95
Neumann, H.—248
Newkirk, Lester L.—188
Newman, Ezra—208
Newman, R.—49
Newman, Seymour—121
Newson, Henry W.—55, 62
Newton, R. G.—66, 67
Ney, E. P.—219, 230
Nickols, N. A.—386, 386, 386
Niederer, J.—192
Nielsen, Alvin H.—259, 259
Nielsen, J. Rud—90, 91, 91, 91
Niemann, F. L.—172
Nier, A. O.—220, 343
Nierenberg, W. A.—252, 253, 343, 343, 389
Nishimura, K.—383
Noble, Gordon A.—33
Noble, L. M.—42
Noggle, T. S.—130, 130, 138
Nolle, A. W.—92, 109
Norbeck, E., Jr.—329
Norberg, R. E.—397
Norris, Forrest H.—109
Norton, K. A.—228
Novey, T. B.—330
Novick, R.—288
Nowick, A. S.—45, 129, 136, 136
Noyce, R. N.—380, 382
Nozières, Philippe—165, 165, 321
Nussbaum, R. H.—16
Nyborg, Wesley L.—15

O'Brien, Mary C. M.—298
O'Dell, F. W.—319
Odian, A.—170
Odian, A. C.—350
Offenbacher, E. L.—380
O'Keefe, George—11
O'Kelley, G. D.—163
Okkerse, B.—149, 299
Oldenberg, Otto—210
Oleson, N. L.—393
Oliver, D. O.—347
Olness, J. W.—212, 213
Olsen, J. L.—41
Olson, R. A.—395
Omholt, A.—393
O'Neill, G. K.—29, 344
Ore, Adne,—200
Osborne, Darrell W.—349
Osborne, L. S.—173, 173
Osborne, R. N.—41
Osborne, W. Z.—86
Osher, John E.—185
Overhauser, A. W.—33, 204, 334
Overley, J. C.—387
Overseth, O. E., Jr.—281
Owen, G. E.—271
Owen, George E.—325
Owen, J.—124
Ozaki, S.—340
Ozeroff, W. J.—248

Page, Lorne A.—168
Palfrey, T. R., Jr.—192
Palevsky, H.—8, 55, 182, 204
Palfrey, T. R., Jr.—192
Palmer, Wilfred—138
Panofsky, W. K. H.—375, 376
Parker, G. W.—207, 207
Parker, Sherwood I.—185
Parker, Vincent E.—70
Parkin, B. R.—364
Parkinson, W. W.—203
Paris, C. H.—223
Paskin, A.—148, 148
Passerini, H. J.—283
Patronis, E. T., Jr.—258
Patten, C. G.—184
Patterson, Ashton M.—249
Patterson, D. A.—112
Pattin, H. S.—119
Paul, D. A. L.—68
Paul, E. B.—28, 29, 29, 30, 39, 195, 195
Paul, W.—48, 299
Paul, William—226
Paulissen, G. T.—282
Peacock, C. L.—86
Pearse, C. A.—303
Pearson, G. L.—111, 295, 331
Pease, Jane—46
Pease, Robert L.—46
Peaslee, D. C.—135, 209
Peck, R. A., Jr.—40
Penner, S.—173
Penning, J. R.—162
Pentz, N.—293, 300
Pepinsky, R.—131, 131
Percus, Jerome K.—26, 57, 221, 221
Perez-Mendez, V.—173, 392
Perkinn, D. H.—186
Perkins, Donald H.—184
Perkins, K. L.—13
Perl, Martin L.—385
Perry, J. E., Jr.—93
Peters, C. W.—70
Peterson, E. L.—117
Peterson, Jack M.—178, 179, 179
Peterson, James R.—184
Peterson, Vincent Z.—173
Petrauskas, A. A.—122
Petroff, Michael D.—389
Peshkin, M.—52
Pevsner, A.—64, 185
Pfann, W. G.—140
Phillips, G. C.—95, 95, 96, 96, 96
Phillips, James C.—142
Philippoff, W.—122
Piccioni, Oreste—173, 376
Picus, G. S.—126
Pien, Y. K.—365
Pieper, G. F.—280, 281
Pierce, Louis—198
Pilcher, V. E.—61, 187, 187, 188, 347
Pinajian, J. J.—330
Pineau, Paul—259
Pines, David—25, 124, 165, 165
Pinnick, H. T.—118
Pixley, R. E.—387
Placious, R. C.—167
Plass, Gilbert N.—35
Pleasonton, F.—42
Pleasonton, Frances—263
Plotkin, M.—177
Pohrte, T.—64
Pollak, V. L.—397
Pollard, Ernest—201
Pollard, Ernest C.—200
Pollock, Franklin—66
Pomerantz, M. A.—38
Pond, T. A.—351
Pool, M. L.—172
Porile, Norbert T.—328
Porter, C. E.—195
Porter, F. T.—171
Porter, W. C.—29, 39
Portis, A. M.—124
Potnis, V. R.—42, 170
Potter, Roy F.—53
Powell, D. A.—379, 379
Powell, R. L.—117
Powell, Wilson M.—385, 386, 386, 392
Pratt, G. W., Jr.—145, 222
Preiss, John W.—301
Present, R. D.—266
Preston, W. M.—172
Price, J. E.—20, 94
Price, P. J.—47
Price, W. J.—270
Primak, W.—136
Prince, E.—132
Prosser, F. W., Jr.—88, 94, 163, 324
Pruitt, J. S.—199, 199
Prusch, S. B.—22
Pugh, Emerson M.—115, 115
Putnam, T. M.—9, 245, 246
Pyle, Robert V.—8, 376

Quimby, S. L.—146
Quinn, F. A., Jr.—123
Quinn, J. J.—44
Quisenberry, Karl S.—220

Raboy, S.—43, 56, 330
Radford, H. E.—284
Rado, G. T.—132, 132
Rae, E. R.—347
Rainwater, J.—176, 176, 177
Rainwater, L. J.—63
Raka, E. C.—177
Rall, W.—68
Ralph, D. C.—262
Ramsey, Norman F.—11
Randall, C. A., Jr.—135, 271
Randolph, M. L.—267
Ranken, W. A.—95
Raphael, Robert B.—37
Rappaport, P.—111, 135
Raridon, Richard—258
Rasmussen, John O.—206
Raz, B. J.—223, 336
Read, W. G.—212
Read, W. T., Jr.—295

Reardon, W. A.—68
Redfield, Alfred G.—397
Redman, J. K.—130, 130
Reeves, T.—26
Rehfuss, D. E.—253
Reich, C. W.—96, 96, 96, 327
Reifman, A.—67
Reiling, G. H.—286
Reineks, Z. L.—402
Reiter, R. A.—71
Reitz, J. R.—333
Reitz, John R.—331
Rempfer, Gertrude Fleming—250, 262, 262
Rempfer, Robert Weir—250, 266
Rense, William A.—98
Reppy, John—57
Resnick, Robert—35
Rexroad, Harvey N.—200
Reynolds, C. A.—57
Reynolds, D. C.—111
Reynolds, H. L.—40, 40, 268
Reynolds, J. M.—88, 88
Rhoads, W. C.—84
Rice, M. H.—361
Rice, Philip L.—228
Rice, Stuart A.—284
Rich, Marvin—253
Richards, H. T.—326
Richardson, James T.—87
Ringo, G. R.—176
Risser, J. R.—20, 93, 94, 211
Riste, Tormod—133
Ritchie, R. H.—166, 184
Ritson, D.—185
Ritson, D. M.—64
Rittner, E. S.—49
Robbins, A. B.—280
Roberts, A.—9
Roberts, B. W.—44
Roberts, Donald E.—110
Roberts, L. D.—207, 207, 207
Roberts, T. R.—289, 290
Robertson, Harry S.—288
Robertson, W. W.—91, 99
Robinson, B. L.—171
Robinson, Berol L.—40
Robinson, C. S.—167, 173
Robinson, E. L.—162
Robinson, John E.—145
Robinson, W. A.—254
Robl, H. R.—302
Rodbell, D. S.—133
Rodgers, Eric—265
Rodney, W.—214
Roever, W. L.—98
Rogers, K. C.—72
Rogosa, George L.—258
Rohatgi, Vijay K.—395
Rona, Elizabeth—261
Rose, B.—174
Rose, David—189
Rose, M. E.—207
Rose, M. H.—18
Rosen, J.—63, 176, 177
Rosen, Louis—9, 93, 224, 245, 246, 296
Rosenbaum, B.—218
Rosenblatt, D. B.—129, 380
Rosenblum, B.—13
Rosenfeld, A. H.—72, 209, 385
Rosenthal, Jenny E.—205
Rosenstock, Herbert B.—141
Rosenzweig, Norbert—304
Rosler, L.—62, 179, 296, 296
Ross, A. A.—17, 17, 17, 245, 246
Ross, Marc—337
Rossi, A.—163
Rossi, B.—230
Roth, Laura M.—48
Rothstein, Jerome—74, 147
Rothman, M. A.—164
Rourke, F. M.—187
Rowland, F. S.—224
Ruark, Arthur E.—85, 86, 266
Rubin, Robert J.—221
Rubinow, S. I.—228
Rudd, J. F.—122, 122
Ruderman, Malvin A.—51, 383, 383
Rudinger, George—15
Rudnick, P.—361
Russell, J. L.—96, 96, 96
Rustad, B. M.—30, 30, 62, 70, 336
Rustgi, Moti L.—84, 84
Ruth, R. P.—294

Sachs, A. M.—350
Sachs, R. G.—168, 169
Sadowski, W.—221
Sagane, Ryokichi—174
Sah, C-T.—382, 382
Saibel, Edward—34
Sakai, M.—163
Salkovitz, E. I.—44, 114, 115, 257
Salmi, E. W.—194
Salpeter, E. E.—46
Salter, Lewis—142
Salwen, H.—221
Salzman, Freda—336
Salzman, George—336
Samios, N.—185, 186, 349, 349
Sampson, Douglas—295
Sandmann, W. H.—391, 392
Sandweiss, Jack—385
Saperstein, Alvin M.—303
Saplakoglu, A.—347
Sapp, R. C.—91, 172
Sard, R. D.—377, 386, 386
Sargent, C. P.—343
Sarles, L. R.—282
Sartain, C. C.—260
Sathoff, H. J., Jr.—163
Sato, Hiroshi—24, 133
Saunders, Bernard G.—260
Saunders, M. J.—263, 265
Sawatzky, A.—149
Schaaf, S. A.—362
Schardt, A. W.—85, 162
Scharff-Goldhaber, G.—206
Schectman, R. M.—187
Schein, Marcel—229
Schellenbaum, R. L.—377
Schenck, J.—296
Shepard, R. L.—119
Scherb, F.—230
Scherrer, V. E.—34, 34, 201
Schiff, L. I.—66
Schiffer, J. P.—20, 39, 88, 94, 94, 95, 95, 163, 211, 324
Schillinger, Edwin J., Jr.—10
Schindler, A. I.—44, 114, 115, 257, 334
Schlegel, Richard—73
Schlier, R. E.—53
Schlömann, Ernst—323
Schluter, R.—185
Schmid, L. C.—297
Schmidt, F. H.—162
Schmitt, H. W.—62
Schneider, J.—58
Schneps, J.—64
Schoen, Alan—149
Schoepfle, G. K.—402
Schrack, R. A.—167
Schrank, G.—29
Schreiber, J. A.—121
Schrieffer, J. R.—118
Schroeder, C. M.—172
Schubert, D. C.—14, 301
Schuldt, S.—339, 339, 384
Schultz, H. L.—296, 296
Schultz, T. D.—25, 142
Schulz, G. J.—288
Schulz-DuBois, Erich—287
Schumacher, R. T.—254
Schuman, R. P.—187, 390
Schumann, R. W.—188
Schwartz, C. L.—383, 383
Schwartz, Guenter—258
Schwartz, H. M.—26
Schwartz, M.—185, 186, 349, 349
Schwartz, Melvin—319
Schwartz, R. B.—187, 347
Scwarzschild, A.—30, 30, 336
Schwarzmann, Gertrude T.—73
Schwed, P.—58
Sclar, N.—48, 120
Scolman, T. T.—220
Scott, Arnold H.—110
Scott, Charles J.—365
Scott, D. W.—40
Sears, G. W.—204
Sears, W. C.—203
Seay, G. E.—227
Sebastian, T. C.—134
Seely, L. B., Jr.—227
Seeman, N.—230, 320
Segall, B.—33, 302
Segel, S. L.—282, 282
Seidlitz, Leo—29
Seifert, W. K.—394
Seki, H.—218
Sellers, H. S.—379, 379
Selove, W.—180
Senio, P.—129
Seppi, E. J.—8, 248, 249, 249, 344
Serin, B.—57
Sessler, A. M.—60, 178, 178
Setlow, Jane—201
Setlow, R.—200
Setlow, Richard B.—201
Shacklett, Robert L.—219
Shalek, R. J.—86
Shankland, R. S.—176, 402
Shapiro, Anatole M.—72, 185
Shapiro, M. M.—319
Sharp, W. T.—210
Shatas, R. A.—38
Shattes, W. J.—57
Shaw, H. C.—253
Shelton, Haywood—395
Sheridan, W. F.—27, 202
Sherman, Noah—37
Sherman, P. M.—14
Sherr, R.—195, 197, 231

Sherwood, R. C.—132
Shiel, V. W.—264
Shields, Doug—265, 265
Shields, Howard, 199, 200, 267, 267
Shilts, J.—333
Shiozawa, Lebo R.—132
Shockley, W.—380, 382, 382, 382
Showers, R. M.—225
Shrader, R. E.—213
Shugart, H. A.—253, 343, 389
Shull, F. B.—281
Shuttleworth, R. Allen—54, 54
Sidles, P. H.—137
Siegel, Armand—220
Sill, R. C.—254, 393
Silsbee, H. B.—252, 253, 343, 389
Silsbee, R. H.—213
Silver, A. H.—216, 323, 324
Silver, Robert—388
Silverman, A.—59, 59
Silverstein, E.—319, 320
Silvidi, A. A.—271, 402
Simms, P. C.—207
Simpson, F. B.—247
Simpson, J. Arol—43
Simpson, O. D.—247
Sinclair, R. M.—195
Sinclair, Rolf M.—42
Singer, J.—298
Singer, L. S.—214
Singer, S. F.—229, 231
Singer, Sidney—163
Singh, R. P.—287
Singletary, J. B.—246
Sinnott, K. M.—198
Sirlin, A.—182
Skarsgard, H. M.—224
Skeen, C. H.—86
Skinner, R. E.—251
Skinner, Selby M.—291, 292, 292, 292
Slack, Glen A.—113
Sladek, R. J.—285, 332
Slater, W.—319, 320
Slattery, J. C.—95
Slattery, J. H.—175
Slaughter, G. G.—64, 177, 186, 218
Slepian, Joseph—182, 342, 351
Sloan, D. H.—394
Slobodrian, R. J.—253
Slovacek, R. E.—183, 188
Smaller, Bernard—124, 125, 324
Smith, A. B.—281
Smith, A. G.—263, 265
Smith, B.—179
Smith, Bob H.—178
Smith, Charles S.—205, 333
Smith, D. F.—259
Smith, Donald O.—396
Smith, E. C.—71
Smith, Frances M.—184, 186, 386, 386, 386
Smith, H. L.—281
Smith, J. R.—327
Smith, P. L.—204
Smith, R. J.—114
Smith, R. V.—55, 175
Smith, Stephen J.—287
Smith, Thomas S.—270, 270
Smith, W. R.—18
Smoluchowski, R.—141
Snell, Arthur H.—42, 263
Snell, Philip A.—301
Snider, J. W.—116
Snow, G. A.—64
Snowdon, S. C.—55
Snyder, Allen L.—186
Snyder, J. N.—61, 178, 178
Snyder, W. S.—32
Sokoloff, J.—303
Solmitz, F. T.—72, 385
Solt, I. H., Jr.—12
Sonder, E.—149
Sonder, Edward—111
Sood, P. C.—269
Sosin, A.—129
Soule, D. E.—255
Speck, D. R.—282
Spencer, E. G.—23, 323
Spencer, L. V.—37
Spencer, R. R.—95
Sperduto, A.—39, 212, 223, 223
Spicer, W. E.—112, 285
Spiegel, V., Jr.—347
Spinner, S.—214
Spiro, J.—177
Spitzer, W.—331
Spitzer, W. G.—126
Spry, W. J.—214
Staats, P. A.—260
Stahl, Ralph H.—178, 179, 179
Stallwood, R. A.—9, 71
Stamper, A. L.—333
Stanton, H. E.—341
Starfelt, N.—10
Stark, D. H.—186
Starner, J. W.—171, 389
Statz, H.—144, 322, 322
Steenberg, N. R.—193
Steffen, R. M.—42, 207
Steele, M. C.—218, 225
Stegun, I. A.—22
Stehle, P.—344
Steigert, F. E.—280
Stein, H. J.—127
Stein, M. L.—339, 339
Stein, P. C.—170
Stein, Richard S.—109
Stein, W. E.—96, 281
Steinberger, J.—185, 186, 349, 349
Steiner, Robert L.—268
Steininger, D. H.—227
Steinitz, R.—54
Stelson, P. H.—164, 164, 183, 263, 264
Stephens, William E.—340
Stephenson, C. V.—257
Stephenson, John L.—203
Stern, Donald M.—121
Stern, Frank—214
Stern, M. O.—72
Sternglass, E. J.—38, 38, 301
Sternheimer, R. M.—193
Steuer, M. F.—339
Stevens, D. K.—117
Stevenson, M. L.—174, 209
Stewart, A. B.—271, 271
Stewart, John W.—218
Stewart, L.—296
Stewart, Leona—93
Stewart, M. G.—206
Stiller, B.—319
Stirling, W. L.—291
Stitt, R. K.—391, 392
Stoltzfus, Joseph—329
Stone, R. S.—183
Storey, W. H., Jr.—86
Stork, Donald H.—184
Stout, V. L.—279
Straley, Joseph W.—259
Stratton, Roy F.—259
Strauch, K.—192
Street, J. C.—172
Strick, E.—98
Strom, P. O.—343, 389
Strominger, Donald—206
Stubbins, Warren Fenton—178
Stull, V. Robert—35
Stump, R.—351
Sturm, W. J.—114
Sugarman, Nathan—328
Sugarman, R. M.—183
Sugawara, M.—304
Sun, C. R.—253
Sun, R.—144
Summers-Gill, R. G.—253, 253
Sunderland, R.—252
Sutton, R. B.—9, 71
Svantesson, N.—21, 28
Svonavec, Michael—10
Swami, M. S.—64
Swank, R. K.—183
Swann, C. P.—29, 39, 211
Swanson, D. C.—261
Swanson, J. A.—117
Swanson, W. E.—322
Swanson, William P.—376
Swartz, C. A.—225
Swartz, C. D.—325
Sydoriak, S. G.—289, 290
Symon, K. R.—178, 178, 344

Taft, H. D.—297
Takahashi, Yasushi—169
Takagi, Yutaka—132
Takeo, Makoto—245
Talbot, L.—362
Tanaka, Katsumi—66
Tannenwald, P. E.—126
Tanttila, W. H.—215
Tatro, C. A.—192
Tauer, K. J.—148, 148
Tautfest, G. W.—375
Taylor, A.—62
Taylor, Charles J.—178, 179, 179, 188
Taylor, J. C.—300
Taylor, J. H.—111, 120
Taylor, R. E.—375
Taylor, R. I.—69
Taylor, William J.—32
Tchen, C. M.—15
Teegarden, K. J.—113
Telegdi, V. L.—63, 319, 320
Tellep, D. M.—362
Temmer, G. M.—43, 164
Tendam, D. J.—29
Teng, Lee C.—178
Thaler, R. M.—89, 89, 89, 384
Theimer, O.—90
Theimer, Rose—91
Theodorides, Phrixos J.—361
Theus, R. B.—10
Thirring, Walter—337

Thomas, D. G.—348
Thomas, G. E.—165, 187
Thomas, H. C.—260
Thomas, L. H.—26, 210
Thomas, R. F., Jr.—86
Thompson, D. O.—130
Thompson, M. C.—228
Thomson, J. O.—214
Thomson, Robb—142
Thorn, R. J.—341
Thornton, W. A.—301
Thurlow, V. S.—98
Thurston, W. H.—397
Tilton, G. R.—31, 31
Tipton, Isabel H.—268
Tobin, R.—340
Tobin, R. A.—192
Tobocman, W.—65, 194, 194
Toll, John S.—66
Tomasch, W.—300
Tomboulian, D. H.—225, 334, 334
Tomizuka, C. T.—149, 150, 150
Tomizuka, Carl T.—149
Tomlinson, E. P.—296, 329
Tomnovec, F. M.—31, 253, 378, 391
Tompkins, J. E.—323
Toms, M. Elaine—192, 340
Torrey, H. C.—216, 282
Treaftis, H. N.—334
Tredgold, R. H.—292
Treiman, S. B.—169
Treuting, R. G.—333
Triebwasser, S.—190
Trigger, Kenneth R.—220
Trilling, G. H.—251
Tripp, R. D.—385
Trivisonno, N. M.—292
Troubetzkoy, E.—336
Tsai, Yung Su—327
Tsao, C. H.—375
Tucker, C. W., Jr.—129
Tucker, G. L.—117
Turkevich, Anthony—94
Turnbull, D.—334, 334
Turner, C. M.—134, 177
Turner, E. B.—361
Tutihasi, Simpei—110
Tyler, W. W.—31, 49, 127, 127

Überall, H.—209
Ufford, C. W.—302
Umeda, K.—26
Uretsky, J. L.—387
Utterback, N. G.—328

Valk, H. S.—169
Van Allen, J. A.—230, 230
Van Horn, David D.—149
Van Patter, D. M.—39
Van Ostenburg, D. O.—205
Van Roggen, Arend—215, 266
Van Roggen, Lien—215, 266
Van Rossun, L.—186, 385
Van Tuyl, H. H.—62
Van Vleck, J. H.—11
Van Vliet, K. M.—320
Varner, W. R.—250
Varwig, Robert—18
Vatsia, M. L.—265
Vaughan, W.—141
Vedder, James—174
Vegors, Stanley H., Jr.—206
Velinsky, L.—174
Venable, W. H., Jr.—261
Venables, J. D.—331
Vestine, E. H.—83
Vineyard, George H.—44, 147
Vining, T. F.—98
Violet, Charles E.—185
Visscher, W. M.—16, 17, 17
Von Herrmann, P.—281
Vrancken, M. N.—123
Voss, R. G.—61

Wachtel, M. M.—38, 38
Wackerle, J. D.—351
Wada, W. W.—181
Wadey, W. G.—179, 296, 296
Wagener, S.—293
Waldorf, W. F.—192
Walker, C. B.—138
Walker, L. R.—125
Walker, R. M.—11, 324, 334, 335
Wall, N. S.—192
Wallace, Roger—186, 251
Wallis, George—52
Wallis, Richard F.—45
Wallmann, J. C.—396
Walmsley, R. H.—57
Walsh, J. M.—361
Walsh, P. J.—287
Walsh, W. M., Jr.—117
Walt, M.—176, 176, 194
Walters, A. E.—62, 296, 296
Walters, G. K.—218
Walton, R. B.—211, 326
Wang, Shyh—52
Wang, P. K. S.—258
Wangsness, Roald K.—11, 126
Waniek, R.—191
Waniek, R. W.—219, 226
Warburton, E. K.—325
Warburton, F. W.—384
Ward, T. J.—330
Warren, G. W.—171, 171
Warren, J. L.—44
Warren, K. L.—402
Warschauer, D.—299
Warschauer, D. M.—226
Watanabe, Satosi—47
Watkins, G. D.—11, 324
Watson, W. K. R.—383, 383
Watson, W. W.—281
Watt, L. A. K.—323
Wattenberg, A.—170, 340
Watters, H. J.—20
Watts, G.—200
Weatherly, T. L.—341
Webb, M. B.—138
Webb, W. H.—40
Weber, A. H.—134
Weber, Gustav—94, 196, 210
Weber, J.—47, 133
Wechsler, M. S.—114
Wechsler, Monroe S.—114
Weddell, J. B.—55, 339
Weeks, Robert A.—12
Weertman, J.—45, 348, 351
Wegener, Peter P.—362
Wegner, H. E.—21
Weil, J.—212
Weil, J. L.—326
Weinberg, Irving—92, 92
Weinrich, M.—174
Weinstein, R.—170, 340
Weinstock, Bernard—349
Weir, C.—214
Weisberg, L. R.—146
Weisberg, Leonard R.—146
Weiser, Kurt—294
Weiss, R. J.—148, 148, 148, 148
Weizel, W.—166
Wellner, Marcel—337
Welton, T. A.—60, 60, 74
Weneser, J.—181, 330
Wenzel, William A.—186, 376, 376
Werntz, J. H., Jr.—349
Wert, C.—150, 150
Wert, Charles—150
Wertheim, G. K.—128, 295, 331
West, Kenneth—402
Westberg, Russell G.—395
Westbrook, R. D.—119
Westervelt, Peter J.—15
Wetherill, G. W.—31, 31
Weyl, P. K.—87, 87
Whalen, J. A.—167
Whaley, R. M.—192
Whaling, W.—387
Wheeler, R. G.—111
Wheelon, Albert D.—228, 377
Whetstone, Albert L.—192
Whetten, N. Rey—279, 279
Whitaker, W. A.—86
White, A. V.—123
White, F. A.—249
White, G. K.—49
White, R.—34
White, R. L.—12
White, R. Stephen—185
Whitehead, Marian—184
Whitehead, W. D.—339
Whitehurst, R. N.—265, 265
Whitmer, R. F.—27
Whitsett, Charles R.—111
Widgoff, M.—64, 185
Widom, B.—203
Wieder, H. H.—254
Wiegand, D. A.—205
Wightman, A. S.—52
Wikner, N. F.—252, 252
Wilkening, Marvin—35
Wilkinson, M. K.—190
Willard, H. B.—54, 264, 346
Willardson, R. K.—54, 332
Williams, H. Bartel—342
Williams, H. J.—132
Williams, John H.—338
Williams, Quitman—341
Williams, W. S. C.—392
Williamson, R. M.—196, 264
Willis, William—290
Wills, James E., Jr.—175
Wilson, E. Bright, Jr.—197
Wilson, R.—59, 59
Wilson, R. R.—172
Wilson, Richard—61
Winans, J. G.—384
Winckler, John R.—229
Winder, R. O.—290
Windle, J. J.—34
Winick, H.—350
Winkler, Stanley—15, 74

Winslow, G. H.—341
Witmer, Enos E.—72
Wolcott, Norman M.—204, 289, 289
Wolfenstein, Lincoln—36
Wolicki, E. A.—165, 196, 197, 211, 211, 325, 325
Wolke, R. L.—165
Wollan, E. O.—190
Wolsky, S. P.—294
Wong, Calvin—175, 388
Wong, David Y.—66
Wood, D. E.—246
Wood, J. H.—222
Woodbridge, David—250
Woodbury, H. H.—127, 127
Woodcock, R. F.—45
Woods, F. R.—36
Woods, Robert, Jr.—142
Woods, Roger D.—45
Woods, S. B.—49
Woodward, W.—59, 59
Woodyard, J. R.—396
Woollett, A. H.—91
Wooten, B. A.—350
Worcester, J. L.—343
Work, Richard N.—109
Worley, R. Edwin—259
Worsham, R. E.—60, 60
Wright, Byron T.—253
Wright, Robert W.—386, 386
Wu, C. S.—30, 41, 68, 336
Wu, T. T.—73
Wyckoff, J. M.—197, 284
Wyly, L. D.—258, 264

Yager, W. A.—321
Yagoda, Herman—64, 229, 297
Yamagata, T.—350
Yang, C. N.—222
Yang, H. T.—362
Yao-Tsu, T.—364
Yarmus, Leonard—13
Yarnell, J. L.—281
Yeater, M. L.—8
Yekutieli, G.—64, 320
Yergin, Paul F.—192
Yevick, George J.—26, 57, 221, 221
Yih, C. S.—363
Yoon, T. S.—319
Yoshiki, H.—231
Young, D. R.—50, 50, 191
Young, F. W.—139
Young, J. M.—122
Young, J. R.—301
Young, O. B.—319
Young, Otis B.—230
Young, T. E.—95, 95
Yu, S. P.—322
Yuster, P. H.—124, 125
Yuster, Phillip—324

Zachariasen, F.—168, 383, 383
Zahlan, A.—216
Zähringer, J.—344
Zand, Robert—121
Zeidman, B.—325
Zeiger, H. J.—117
Zemany, P. D.—279
Zemel, Jay—18, 38
Ziering, S.—227
Zimmerman, John R.—92, 92, 92
Zimmerman, R. L.—8, 182, 347
Zingery, W. L.—92, 92
Zinnes, Irving—85
Zipoy, D.—9, 338
Zuchelli, A. J.—68
Zucker, A.—40, 40, 193, 268
Zwerdling, S.—299, 299